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SUMMARY

This investigation of an air ejector employing a supersonic primary flow and a subsonic secondary flow was made to determine the mechanics of mixing. It was concluded that the mechanics of mixing consists of two phenomenon: a) static pressure equalization - herein called pressure mix, and b) establishment of the velocity profile involving momentum transfers between the two airstreams.

It was found that pressure mix and establishment of the velocity profile were completed at different points along the mixing tube. These points were quantitatively affected by primary and secondary stream variables as well as discharge pressures.

This investigation was conducted as a thesis in partial fulfillment of the requirements for an M. S. Degree at Rensselaer Polytechnic Institute. The work was performed under the guidance of Professor N. P. Bailey and assisted by Professors H. A. Wilson and F. J. Bordt.

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INTRODUCTION

This is a report on an investigation of an air ejector with a supersonic primary and a subsonic secondary. The investigation was made to determine the mechanics of the mixing process.

Existing literature contains few attempts to explain the mechanics of mixing and no information on supersonic and subsonic mixing. Accordingly, attention was directed to the phenomenon of mixing.

This investigation was conducted as a thesis in partial fulfillment of requirements for a M. S. degree at Rensselaer Polytechnic Institute. The work was performed under the guidance of Professor N. P. Bailey. Equipment used is located in the Rensselaer Polytechnic Institute, Troy, New York.

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EQUIPMENT AND PROCEDURE

Fig. 1 indicates the physical arrangement of the primary-secondary configuration. The primary nozzle was made of bronze and highly polished. The secondary passage was formed by the belled-mouth of a copper mixing tube and the machined and polished outer surface of the primary nozzle.

The primary air supply was furnished by a standard 175 CFM, reciprocating, Schramm electric driven compressor. The primary air supply was cooled, metered, and screened prior to delivery to the nozzle. Secondary air flow depended wholly on atmospheric conditions. This arrangement, although actually a blower, embodied the characteristics of the air ejector.

Static survey equipment consisted of .10" diameter steel and copper tubes so mounted that alignment with the flow was readily obtainable. Also various static pressure wall taps were mounted along the length of the mixing tube. Impact survey equipment consisted of probes made of tubes varying in diameter from that of a surgeon's hypodermic needle to .10".

A standard 3/4" ASME nozzle was used to meter primary flow. A standard 4 3/8" flange orifice in a 6" pipe was used to meter total flow for purposes of calibration of the secondary nozzle.

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The primary nozzle was designed in accordance with existing theory to discharge without shock at sub-atmospheric pressure and at a Mach Number of approximately 2.3. This nozzle was calibrated against the 3/4" ASME nozzle mentioned and the coefficient determined. (See sample calculations).

Calibration of the secondary nozzle was accomplished by simultaneously metering total and primary flows, while recording secondary throat pressures. Discharge coefficients were determined for various secondary pressure ratios as shown in Figure 2, and in sample calculations.

Schlieren photography employed a standard arrangement utilizing a device for spark photography.

On the initial runs static pressure centerline surveys were made from a point near the primary nozzle throat to the downstream point at which the pressure oscillations were damped out. Static pressure surveys across the diameter of the mixing tube were then made at positions upstream and downstream from this point. In addition, impact surveys were made to determine velocity distributions.

The above procedures were duplicated at various mixing tube lengths. Furthermore, a static pressure centerline survey of the primary nozzle discharge into the atmosphere was recorded and a Schlieren photograph taken. A photograph was also taken of the nozzle discharge free of the centerline traverse.

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RESULTS AND DISCUSSION

Figures 3, 4, 5, 6 illustrate that in the mixing of a supersonic and a subsonic stream at different total and static pressures two distinct phenomenon are present. One of these involves the equalization of static pressures. The other involves the growth and establishment of the normal turbulent velocity profile. Under the conditions of this investigation these two phases were not completed simultaneously, but were in separate stages of development along the mixing length.

Figures 3, 4, 7 are sample illustrations of the fact that in all tests performed the "static pressure mix" occurred prior to the establishment of the normal turbulent velocity profile. For the remainder of the discussion the following definitions will apply: a) Static pressure mix is that point beyond which the static pressure is constant across the diameter of the mixing tube; b) Mixing length is that length at which the velocity is essentially constant along the diameter and the static pressure mix has occurred. In no case was the static pressure of the primary and secondary equal at the mixing tube throat. This was true despite the fact that ample area ratios were provided for the pressure ratios expected due to the primary discharge pressure.

Attempts to isolate the effect of mixing tube length on the "mixing length" were inconclusive since it was not possible

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to control secondary supply* and mixing tube discharge pressures. Results obtained, therefore, show only the total effect of the combination of a variable secondary supply pressure, variable discharge pressure and a variable mixing tube length. Moreover, the effect of these pressures varying with barometric conditions made day by day duplication of results impractical. However, the data were compatible with the conclusions of the preceding paragraphs.

It was found that insertion of probe equipment in the mixing tube affected both primary and secondary flow. This effect became appreciable as the primary nozzle exit was approached. Tests indicated that probes downstream from a mixing tube length of 3" or more exerted only minor effects on the primary and secondary variables, provided a surgeon's hypodermic needle was used as a probe.

This interference with flow forced the adoption of some alternate means of determining the early adjustments experienced by the two streams, since all attempts to analyze occurrences using plane and two dimensional angle shock theory were to no avail. In order to obtain some indication of the sequence of events and to attempt application of shock theory, Schlieren photographs of free jet discharges, with and without center traverse tube, were made. (See Figures 8, 9, 10).

* The secondary supply pressure was not controlled due to the non-availability of equipment; i.e. the only compressor available was fully employed supplying primary flow.

A stable shock pattern was obtained without the center traverse tube. However, with the center traverse in the nozzle, shock pattern varied with transverse vibrations of the tube. Despite the variation in shock pattern, the mechanics of mixing basically remained unchanged.

Figures 3, 4, 7 illustrate variations in the location of the point at which static pressure oscillations were damped out. This damping out process was evident in all runs. To determine its significance, impact and static pressure surveys were made upstream, downstream, and at the point in question. Figure 11 is indicative of the results of the static pressure surveys and shows that at the point in question static pressures have equalized across the diameter. Figures 12 and 13 are sample indications that, in addition, the velocity profile is not fully developed at the time of pressure mix.

Having determined the point of pressure mix and its significance, the problem resolved into the determination of mixing length as previously defined. Figures 5, 6, and 13 again illustrate the actual development of the velocity profile at different stages along the mixing tube length. It was found that the development of the velocity profile required a definite length of mixing tube before becoming essentially constant across the diameter. For example, in Figure 6, 13 the velocity profile is not considered fully developed at discharge. However, as shown by Figure 21 the profile is considered to be fully developed prior to discharge.

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Study of Table IX, that run in which under the given conditions of flow, the mixing length was a minimum, shows that the static pressure continued to rise until discharge. Since subsonic flow in a constant area tube should have been accompanied by a pressure drop, further investigation was warranted. It was felt that the pressure rise was due to the overall effect of the momentum transfers between primary and secondary streams, resulting in a diffusion effect. To confirm this point, excessive mixing tube length was used and it was found that the pressure rose to a maximum, followed by the pressure drop normally expected in subsonic flow at constant area and with friction. (See Table X). This behavior indicated that during the pressure rise the effect of momentum transfers overcame friction effects and when the pressure reached a maximum friction again governed the flow with momentum transfers becoming less and less effective.

To determine the effect of probe equipment on the flow conditions, tests were made with and without the diameter probe. As shown in Figures 4, 7, 14 and tables pertaining thereto, the flow was affected considerably by the probe equipment used in the tests. Accordingly, runs were made to determine the effect on the flow of probes of various sizes and shapes, consistent with the requirements in accuracy. It was found that most accuracy and minimum flow interference was obtained when probes were made through a small hole in the mixing tube wall, using a goosenecked probe made of a 3 1/2" hypodermic needle. It should be noted however, that

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all probe equipment affected the flow to some extent. This points to the advisability of employing as large a configuration as possible to minimize these effects and to enable more accurate information to be obtained.

Due to the large amount of interference from even the smallest probe equipment along the first few inches of the mixing tube, no accurate data was obtainable in this portion. This interference was evidenced by not only a change in instrumentation readings, but a change in the sound of the flow.

Schlieren photographs (Figures 8, 9, 10) emphasize that the center traverse tube changed the type of shock and generally destroyed the symmetry. In addition, transverse vibrations of the tube rendered the shock pattern unstable. For example, Figure 8 shows a pattern which was observed to be symmetrical and stable. On the other hand, Figure 9 shows fewer rarefactions and more angle shocks. Although not shown by Figure 9 the shock pattern continuously changed with transverse tube vibrations. In addition, a change in the distance between supports of the center line traverse tube also changed the shock pattern as is illustrated in Figure 10. It is thought that this change was brought about by the difference in the amplitude of the transverse vibrations and that the larger the amplitude of these vibrations the more angle shocks will be induced with subsequent reduction in the number of rarefactions present. Again it is desired to emphasize that the variations in the shock pattern do not alter the mechanics of mixing as

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previously mentioned. Tests performed with and without the centerline tube in position indicated solely quantitative effects. (See Figure 11, which illustrates pressure mix without center traverse tube in nozzle and Figure 21 which illustrates the velocity profile development in the absence of a centerline traverse tube).

In all cases the static pressure surveys indicated that in adjustment to pressure equilibrum between the two streams, the primary flow experienced a series of shocks and rarefactions. Such a condition would always be expected where the static pressure of the primary was lower than that of the secondary (and at best it would only be equal, never greater). Although no data of this experiment is applicable, it seems reasonable to expect shock conditions in any ejector operation involving supersonic flow or flows. Since the process is essentially one of entrainment of the secondary by the primary, the supersonic primary will encounter air masses of the subsonic secondary (or possibly a supersonic secondary). These air masses will constitute an interference as far as the primary is concerned and, since the disturbance effect cannot be propagated upstream, shock of the primary airstream will result. In the case where each of the two flows is supersonic, the faster stream will shock first and in cases where shock or shocks bring the primary velocity below secondary velocity the secondary stream will shock. This sequence will probably continue until the streams are at the same velocity or until both are subsonic.

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Any investigation of a supersonic free jet discharge precludes the possibility of direct measurement due to interference effects. Hence some indirect means is necessary. It is thought that simultaneous employment of Schlieren and Interferometric photography would solve this problem. Through the use of this equipment the location and types of shocks would be known along with the static temperatures at the points desired. Therefore, since total temperatures are known, Mach numbers before and after the shocks could be computed and pressure ratios determined. For example, if the location of shocks (as in Figure 8) were accurately known, and static temperatures measured at pertinent points, the validity of existing theory could be tested.

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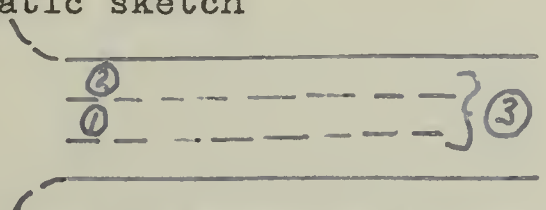
ANALYTICAL DISCUSSION

Basically, there are two sources of relationships between variables involved in air ejectors: namely; energy and momentum concepts. In order to simplify the relationships involved between variables in the computation of mixing length, Mach Number can be and is used as a working variable.

Application of the momentum theory requires the following two assumptions: 1) weight flows in the two relative channels remain individually constant, and 2) the areas of the flow channels along the mixing length remain unchanged. Using the notation numerically indicated in the following diagrammatic sketch



and applying the momentum theory to the primary stream:

$$\frac{W_1}{g}\, dv_1 + a\, dP_1 + dF_{air} = 0 \qquad (1)$$

Similarly for the secondary stream

$$\frac{W_2}{g}\, dv_2 + (A-a)\, dP_2 - dF_{air} + dF_{wall} = 0 \qquad (2)$$

Adding (1) and (2)

$$a\, dP_1 + (A-a)\, dP_2 + \frac{W_1}{g}\, dv_1 + \frac{W_2}{g}\, dv_2 + dF_{wall} = 0 \qquad (3)$$

Defining dF_{wall} :

$$dF_{wall} = + \frac{\rho v^2}{2}\, \pi D\, dl \qquad (3a)$$

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(3) becomes

$$a\,dP_1 + (A-a)\,dP_2 + \frac{w_1}{g}dv_1 + \frac{w_2}{g}dv_2 + f\,\frac{\rho V^2}{2}\pi D\,dl = 0 \quad (3')$$

Equation (3') can be integrated directly if the mean value of ρ and V^2 are used such that

$$\left.\begin{aligned} \rho &= \sqrt{\rho_2\,\rho_3} = \rho_{2m} \\ V^2 &= V_2 V_3 = V_{2m}^2 \end{aligned}\right\} \quad (4)$$

Using equations (4) and (3') and integrating from the ejector throat to the point (3) where the velocities and static pressures are equal for the two streams:

$$a(P_3-P_1) + (A-a)(P_3-P_2) + \frac{w_1}{g}(v_3-v_1) + \frac{w_2}{g}(v_3-v_2) + \frac{\rho_{2m}v_{2m}^2}{2}\pi D l = 0 \quad (5)$$

Solving for l:

$$l = \frac{1}{f\pi D}\,\frac{2}{\rho_{2m}V_{2m}^2}\left[a(P_1-P_3) + (A-a)(P_2-P_3) + \frac{w_1}{g}(v_1-v_3) + \frac{w_2}{g}(v_2-v_3)\right] \quad (6)$$

Using

$$\rho = \frac{P}{gRT}\,, \quad M = \frac{v}{\sqrt{\gamma g R T}} \qquad (7)$$

and changing to Mach notation:

$$l = \frac{1}{f\pi D}\,\frac{2}{\gamma P_{2m} M_{2m}^2}\left[P_1 a(1+\gamma M^2) + P_2(A-a)(1+\gamma M_2^2) - P_3 A(1+\gamma M_3^2)\right] \quad (8)$$

Rearranging to obtain dimensionless parameters:

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$$\frac{f\gamma l}{2m} = \frac{P_3}{P_{2m} M_{2m}^2}\left[\frac{P_1}{P_3}\frac{a}{A}\left(1+\gamma M_1^2\right) + \frac{P_2}{P_3}\frac{A-a}{A}\left(1+\gamma M_2^2\right) - \left(1+\gamma M_3^2\right)\right] \text{ — } (9)^*$$

By assuming constant total energies and constant specific heats

$$W_1 T_{01} + W_2 T_{02} = W_3 T_{03} \text{ —— } (10)$$

$$\sqrt{T_{01}}\left(W_1\sqrt{T_{01}}\right) + \sqrt{T_{02}}\left(W_2\sqrt{T_{02}}\right) = \sqrt{T_{03}}\left(W_3\sqrt{T_{03}}\right) \text{ — } (11)$$

Since $\frac{W\sqrt{T_0}}{PA} = M\sqrt{\frac{\gamma g}{R}\left(1+\frac{\gamma-1}{2}M^2\right)}$ for the tube flowing full with velocities constant across the respective flows eq. (11) rearranges to:

$$\sqrt{\frac{T_{01}}{T_{03}}}\,\frac{P_1}{P_3}\,\frac{a}{A}\,M_1\sqrt{1+\frac{\gamma-1}{2}M_1^2} + \sqrt{\frac{T_{02}}{T_{03}}}\,\frac{P_2}{P_3}\,\frac{A-a}{A}\,M_2\sqrt{1+\frac{\gamma-1}{2}M_2^2} = M_3\sqrt{1+\frac{\gamma-1}{2}M_3^2} \text{ — } (12)$$

It should be noted that equations (9) and (12) apply despite shock conditions of any type and hold within the restrictions of the original assumptions.

* Equation (9) could have been derived by noting that the total momentum per second (in pounds) past any point is PA($1+\gamma M^2$), and that $\int d\left[PA(1+\gamma M^2)\right] = -\int F dx$ since $\int P dA = 0$. Defining F as any external force such as friction or obstruction and in this case as in equation (3a), the relations of eq. (9) are obtained.

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Eq. (12) relates initial and final conditions. Knowing the initial conditions for both primary and secondary flows, a relation between M_3 and P_3 is established. This relation must be solved by trial and error unless one of the final conditions is known.

Having determined P_3 and M_3 by eq. (12) it is possible to compute directly the value of $\frac{f x l}{2m}$. Examination of Eq. (9) shows that as M_2 approaches 0 the value of $\frac{f x l}{2m}$ approaches infinity. Also when $P_1 = P_2$, $M_1 = M_2$ the value of $\frac{f x l}{2m} = 0$ hence x is 0 and the shortest mixing length results. Furthermore when $\frac{f x l}{2m} \neq 0$, $f = 0$ then l is infinite, showing that without friction, mixing would not occur.

Actually $\frac{f x l}{2m}$ cannot be predicted or calculated unless initial conditions of both primary and secondary are known. In practice this means that both primary and secondary variables must be controlled if mixing conditions for a given installation are to be duplicated. Having the value of $\frac{f x l}{2m}$ it is important that f be determined with care since f is inversely proportional to l, making the final value of l greatly dependent on the f used. Attempts to compute the value of f and thereby predict l in this investigation were handicapped by the narrow range of M_2's which could be obtained. Hence this theory could not be verified over a satisfactory range of operation to prove its validity for all cases.

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The applications of equations (9) and (12) are greatly simplified by the use of curves shown on Figures 15 and 16. One method of application of this theory is illustrated in the preparation of Figures 17, 18 and 19. This example is limited by the following specific conditions:

a) $\frac{P_{01}}{P_{02}} = 5.46 = \frac{P_{01}}{P_3}$

b) $A/a = 3.84$; $\frac{A-a}{A} = .739$

c) $T_{01} = T_{02} = T_{03}$

The complete computation for one point on each curve is shown in the sample calculations.

The utility of these curves is apparent when, considering limitations a, b, c above, and entering the curves of Figure 19 with the primary and secondary Mach numbers given, in Table IX the value of $\frac{f\gamma l}{2m}$ is found. The data of Table IX lists $M_2=2.31$ and $M_2=.574$. Figure 19 then gives $\frac{f\gamma l}{2m} = .447$ Using an $f=.0108$ as given by an $N_R = 2.54 \times 10^4$ in Dodge and Thompson, $l = 15.5''$. This is verified to the extent that at $l = 13''$ the velocity profile is not yet formed, although fairly well developed.

It must be realized that curves similar to the above must be plotted for each case where the limitations such as a, b, c above are different.

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CONCLUSIONS

It is therefore concluded that in air ejectors employing a supersonic primary airstream and a subsonic secondary airstream the mechanics of mixing consists of the following phenomena: a) Static pressure equalization, herein called pressure mix, b) The establishment of a velocity profile involving momentum transfers between the two streams.

In this investigation the pressure mix and the establishment of the velocity profile were completed at different points along the mixing tube. Each was affected quantitatively by primary and secondary variables as well as mixing tube discharge pressure.

RECOMMENDATIONS

It is recommended that in any similar air ejector investigations:

a) Means be provided for accurate control of secondary supply pressure in order to extend the applicable range of the investigation.

b) That an area ratio between secondary throat and primary exit of at least 10 be used and that the mixing tube diameter be at least 3".

c) That a water table investigation of this problem be made for the purpose of further study of the supersonic flow pattern involved and to verify the conclusions of this experiment.

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NOMENCLATURE

L - Mixing tube length, measured from the secondary throat

l - Distance of the point along the mixing tube, measured from the secondary throat

x - Distance from the primary nozzle throat, in eighths of an inch (in Tables)

X - Distance from the primary throat in inches

d - Distance from the mixing tube wall, along a diameter, measured in inches

D - Diameter of the mixing tube

P_x - Static pressure in inches of Mercury

P_d - Impact pressure in inches of Mercury

P_{01} - Total pressure of Primary air supply, psig (same as P_B)

P_1 - Static pressure at primary nozzle exit, inches of Mercury

P_3 - Static pressure at mixing length

P_2 - Static pressure at secondary throat, inches of Mercury

$P_{1\ orifice}$ - Static pressure prior to metering orifice

$\Delta P_{orifice}$ - Pressure drop across metering orifice

P_A - Static pressure prior to metering nozzle, Primary flow

P_B - Discharge pressure of metering nozzle (same as P_{01})

${}_A\Delta P_B$ - Pressure drop across metering nozzle, Primary flow

dP_1 - Differential pressure change in primary stream

dP_2 - Differential change of pressure in secondary stream

T_{01} - Absolute total temperature of primary air

T_{02} - Absolute total temperature of secondary air

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T_{03} - Absolute total temperature at mixing length

T_A - Static temperature ahead of metering nozzle

$T_{1\ orifice}$ - Static temperature ahead of metering orifice

M_1 - Primary discharge Mach number

M_2 - Secondary throat Mach number

M_3 - Mach number at mixing length

M_i - Ideal Mach number (for calibration purposes)

M_a - Actual Mach number (for calibration purposes)

W_1 - Primary weight flow, lbs/sec

W_2 - Secondary weight flow, lbs/sec

W_3 - Total weight flow, lbs/sec

v_i - Ideal velocity, ft/sec

v_a - Actual velocity, ft/sec

dv_1 - Differential velocity change in primary stream, ft/sec

dv_2 - Differential velocity change in secondary stream, ft/sec

C_v - Nozzle velocity coefficient

m - Hydraulic radius, inches

R - Gas constant for air, lbs ft/degree R.

γ - Ratio of specific heats, air

dF_{air} - Differential friction between the primary and secondary streams, lbs.

dF_{wall} - Differential friction between the wall and airstream, lbs.

f - Friction coefficient, Dimensionless

A - Area of mixing tube, sq. in.

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a - Primary discharge area, sq. in.

ρ - Density of air, slugs/ft^3

g - Gravitational acceleration, ft/sec^2

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SAMPLE CALCULATIONS

Example of primary nozzle weight flow computations which were made at multiple pressure ratios without shock occurring in the nozzle:

$\Delta P_{A\,B}$ ("H_2O) = 20.4 × 5.198 = 106 psf

P_B = 76.4 psia = 11000 psf

P_A = 11000 + 106 = 11106 psf

$$\frac{\Delta P}{P_A} = .0104$$

$$W_1 = 8.02\,A\,\frac{P_A}{\sqrt{RT_A}}\sqrt{\frac{\Delta P}{P_A}\left(1-\frac{\Delta P}{P_A}\right)}$$

$$= 8.02(.003065)\,\frac{11106}{\sqrt{53 \times 546}}\,\sqrt{.0104(.9896)}$$

= .163 lbs sec. ←

Now

$$\left(\frac{W\sqrt{T_0}}{PA}\right)_{\substack{\text{nozzle}\\\text{exit}}} = \frac{.163\sqrt{546}}{11.7 \times \frac{14.7}{29.92}(.2215)} = 2.99 \quad \therefore M_{1a} = 2.295$$

$$\frac{P_B}{P_1} = \frac{P_{01}}{P_1} = \frac{76.4}{11.7 \times \frac{14.7}{29.92}} = 13.28 \quad \therefore M_{1i} = 2.338$$

Now

$$C_v = \frac{v_a}{\sqrt{\gamma g R T_0}} \Big/ \frac{v_i}{\sqrt{\gamma g R T_0}} = \frac{1.605}{1.618} = .993 \longleftarrow$$

In order to check this further with weight flow in another case: (DATA IN TABLE)

$\Delta P_{A\,B} = 22.5$ " $H_2O = 117$ psf

$P_B = P_{01} = 77.37$ psia $= 11120$ psf

$P_A = 117 + 11120 = 11237$ psf

$$\frac{\Delta P}{P_A} = .01038$$

$$W_1 = 8.02\,A\,\frac{P_A}{\sqrt{R T_A}}\sqrt{\frac{\Delta P}{P_A}\left(1 - \frac{\Delta P}{P_A}\right)}$$

$$= 8.02(.003065)\frac{11237}{25.3 \times 7.3}\sqrt{.01038(.98962)} = .1627 \text{ lbs/sec.}$$

$$\left(\frac{W\sqrt{T_0}}{P_1 A_1}\right)_{\substack{\text{nozzle}\\ \text{exit}}} = \frac{.1627\sqrt{555}}{11.6 \times \frac{14.7}{29.92} \times (.2265)} = 3.035$$

$$\therefore M_{1a} = 2.31 \longleftarrow$$

Since $\dfrac{P_B}{P_1} = \dfrac{P_{01}}{P_1} = \dfrac{11120}{11.6 \times \frac{14.7}{29.92} \times 144} = 13.55$ Hence $M_{1i} = 2.352$

$$\therefore \frac{v_i}{\sqrt{\gamma g R T_0}} = 1.624$$

Since $\frac{v_a}{\sqrt{\frac{\gamma}{\gamma-1}gRT_0}} = 1.624 \times .993 = 1.61$

This gives $M_{1a} = 2.31$ ←

which checks the above.

For secondary C_v (Row 1, TABLE)

$\Delta P_{A\,B} = 5.198 \times 26 = 135 \text{ psf}$

$P_B = (66.5 + 15.52)\,144 = 11800 \text{ psf}$

$P_A = 11935 \text{ psf}$

$\frac{\Delta P}{P_A} = .0113$

$$W_1 = 8.02A \frac{P_A}{\sqrt{RT_A}} \sqrt{\frac{\Delta P}{P_A}\left(1 - \frac{\Delta P}{P_A}\right)}$$

$$= 8.02(.003065) \frac{11935}{\sqrt{53.3 \times 544}} \sqrt{.0113(.9887)} = .182 \text{ lbs/sec}$$ ←

Metering Orifice (total flow)

$P_{1\,orifice} = 5.198(.44) + 2225 = 22325$

$\Delta P_{orifice} = 5.198(.9) = 4.68 \text{ psf}$

$\frac{\Delta P}{P_1} = .00219$

$$W_{orifice} = W_3 = 8.02A \sqrt{\frac{P_1 \Delta P}{R\,T_{1\,orifice}}} \times C_{v\,orifice}$$

$$W_3 = 8.02(.1045)(.727)\sqrt{\frac{2237 \times 4.68}{53.3 \times 544}}$$

$$= 8.02(.1045)(.727)\sqrt{\frac{2237 \times 4.68}{53.3 \times 544}}$$

$$= .367 \text{ lbs/sec}$$

Hence $W_2 = W_3 - W_1 = .367 - .182 = .185$ lbs/sec

Now $\frac{P_{02}}{P_2} = \frac{31.6}{24.8} = 1.273 \quad \therefore M_{2i} = .593$

and $\frac{V_i}{\sqrt{\delta g R T_0}} = .58$

By actual weight flow as metered:

$$\frac{W_2\sqrt{T_{02}}}{P_2(A-a')} = \frac{.185(23.4)}{.61 \times \frac{14.7}{29.92} \times 24.8} = .584 \quad \therefore M_{2a} = .612$$

and $\frac{V_a}{\sqrt{\delta g R T_0}} = .595$

Hence $C_v = \frac{V_a}{\sqrt{\delta g R T_0}} \Big/ \frac{V_i}{\sqrt{\delta g R T_0}} = \frac{.595}{.58} = 102.6 \longleftarrow$

For the above: $A = .858$

$a' = .248$

$A - a' = .610$

Calculations relative to figures 14, 15, 16

For $M_1 = 2.1$ and $M_2 = .16$

$$\frac{P_{01}}{P_1} = 9.1 \quad \text{and} \quad \frac{P_{02}}{P_2} = \frac{P_3}{P_2} = 1.01$$

$$\frac{P_2}{P_1} = \frac{P_{01}}{P_1} \cdot \frac{P_2}{P_{02}} \cdot \frac{P_{02}}{P_{01}} = 9.1\left(\frac{1}{1.01}\right)\left(\frac{1}{5.46}\right) = 1.648$$

$$\frac{P_1}{P_3}\,\frac{a}{A}\,M_1\sqrt{1+\frac{\gamma-1}{2}M_1^2} + \frac{P_2}{P_3}\,\frac{A-a}{A}\,M_2\sqrt{1+\frac{\gamma-1}{2}M_2^2} = M_3\sqrt{1+\frac{\gamma-1}{2}M_3^2}$$

$$\frac{.261}{1.665}(2.87) + \frac{.739}{1.01}(.103) = M_3\sqrt{1+\frac{\gamma-1}{2}M_3^2}$$

$$M_3\sqrt{1+\frac{\gamma-1}{2}M_3^2} = .5254$$

$$M_3 = .506 \longleftarrow$$

$$\frac{f+f}{2m} = \frac{P_3}{P_{2m}M_{2m}^2}\left[\frac{P_1}{P_3}\,\frac{a}{A}(1+\gamma M_1^2) + \frac{P_2}{P_3}\,\frac{A-a}{A}(1+\gamma M_2^2) - (1+\gamma M_3^2)\right]$$

Since $\dfrac{P_3}{P_{2m}} = \sqrt{\dfrac{P_3}{P_2}\,\dfrac{P_3}{P_3}} = \sqrt{\dfrac{P_3}{P_2}} = \sqrt{\dfrac{P_{02}}{P_2}}$

$$\frac{f+f}{2m} = \frac{1.005}{.0506}\left[\frac{1}{1.665}(.261)(7.22) + \frac{1}{1.01}(.739)(1.003) - (1.56)\right]$$

$$= 10.42$$

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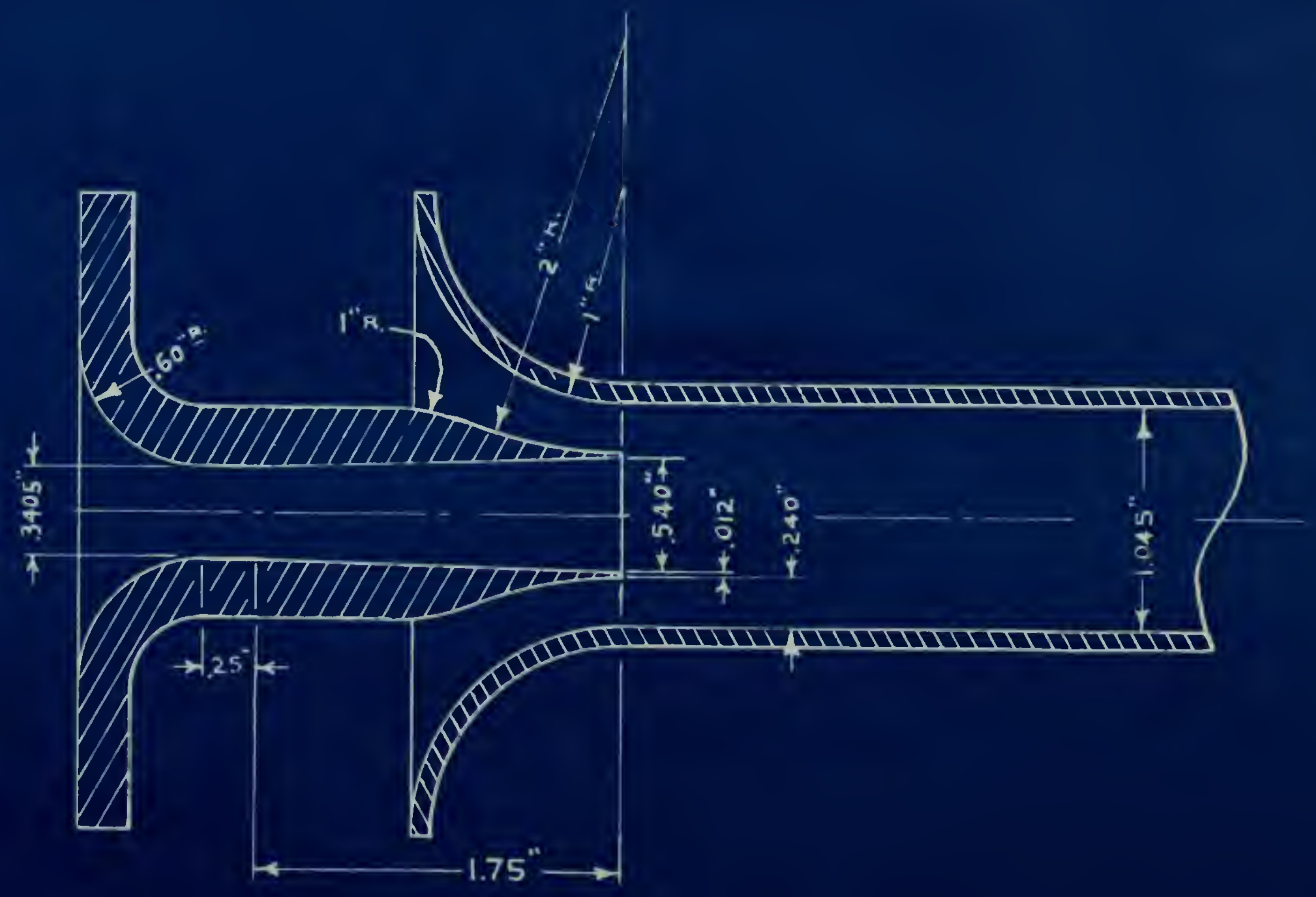


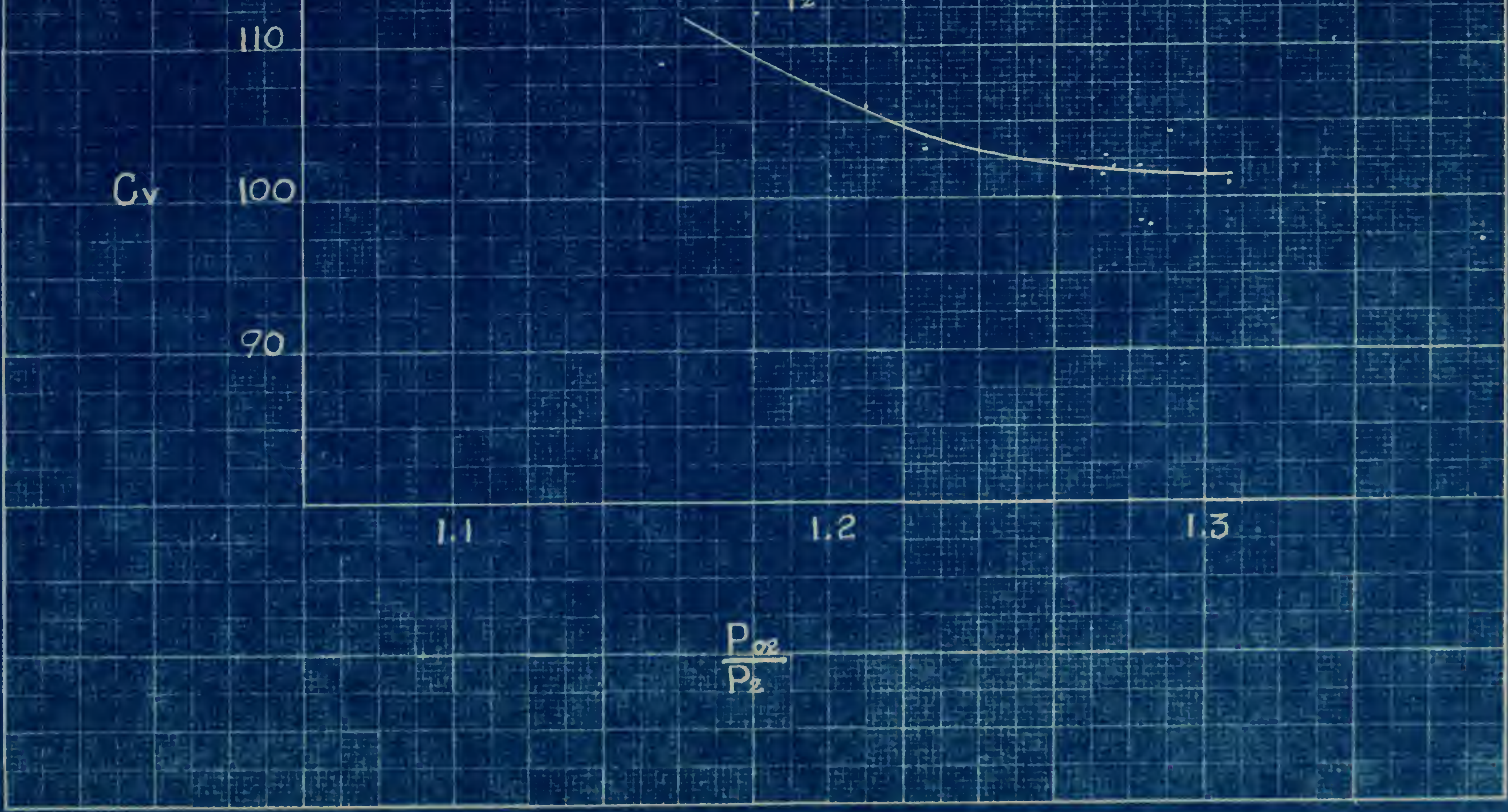
Fig. 1

Primary - Secondary Configuration

Scale - Full

FIG. 2

C_v VS $\frac{P_{o2}}{P_2}$



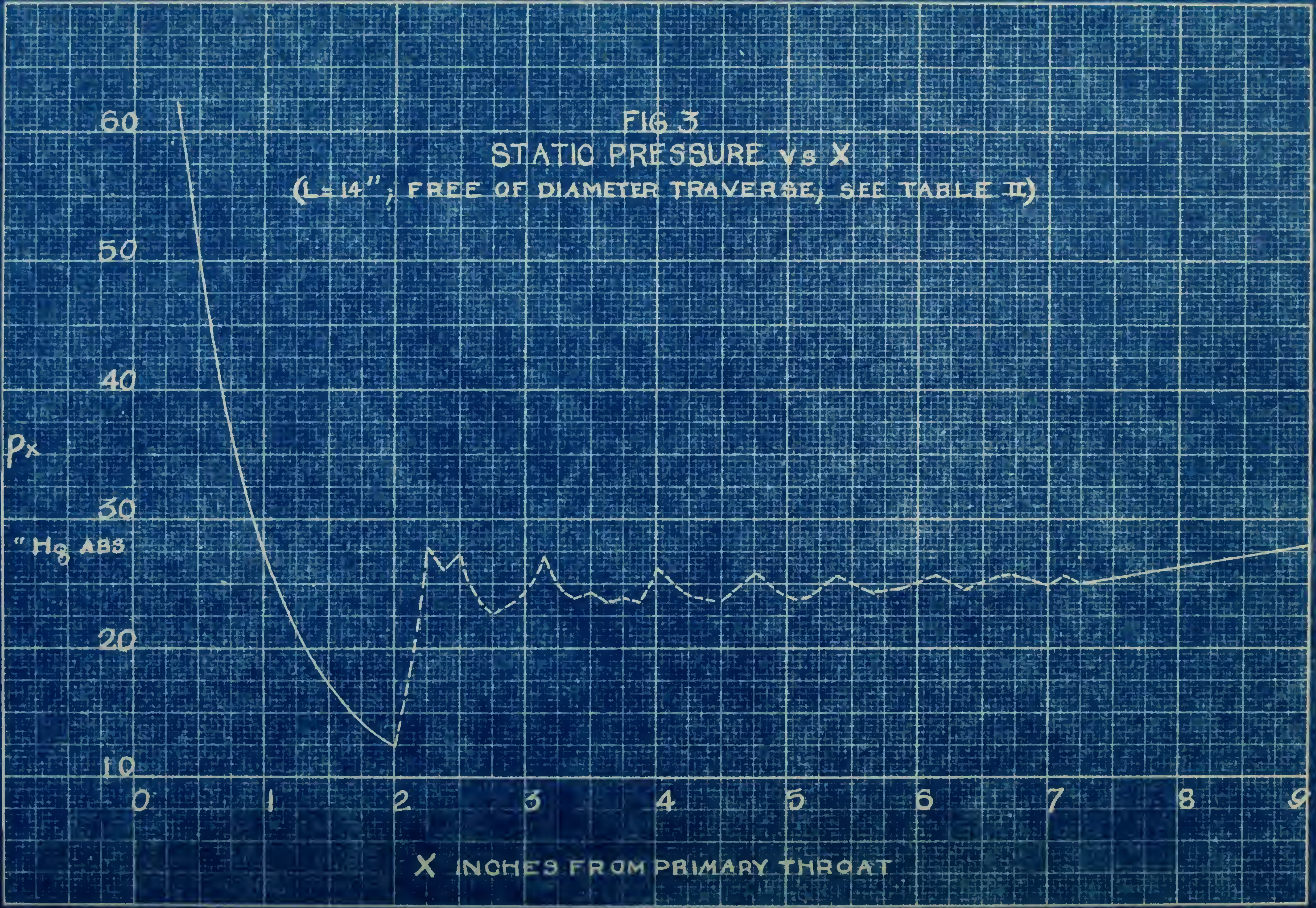


FIG. 3
STATIC PRESSURE vs X
(L=14"; FREE OF DIAMETER TRAVERSE, SEE TABLE II)
60
50
40
30
20
10
px
"Hg ABS
0
1
2
3
4
5
6
7
8
9
X INCHES FROM PRIMARY THROAT

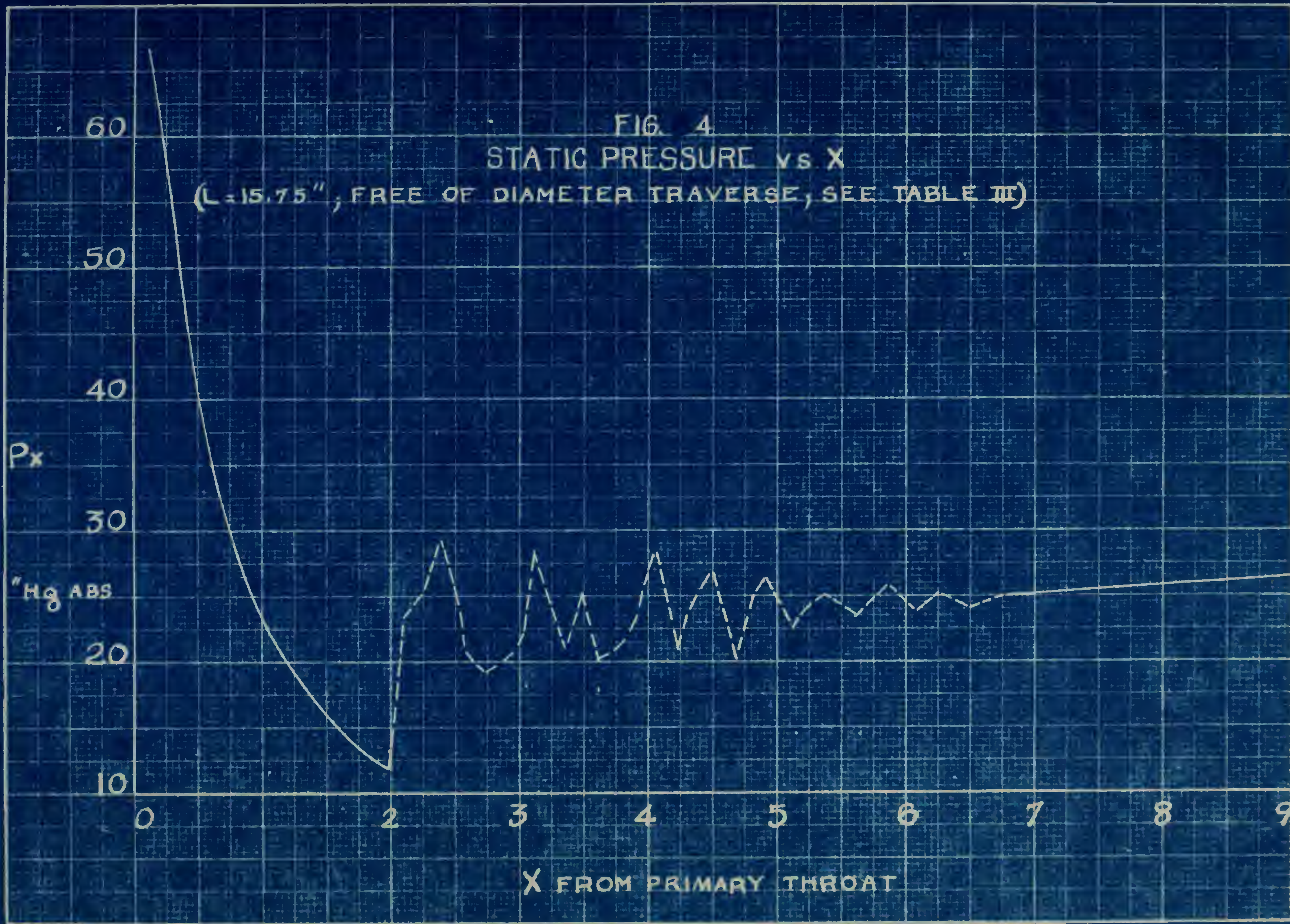


FIG. 4
STATIC PRESSURE vs X
(L=15.75", FREE OF DIAMETER TRAVERSE, SEE TABLE III)
60
50
40
Px
30
"Hg ABS
20
10
0
2
3
4
5
6
7
8
9
X FROM PRIMARY THROAT

FIG. 5

MIXING TUBE DIAMETER vs IMPACT PRESSURE

SEE TABLE IV

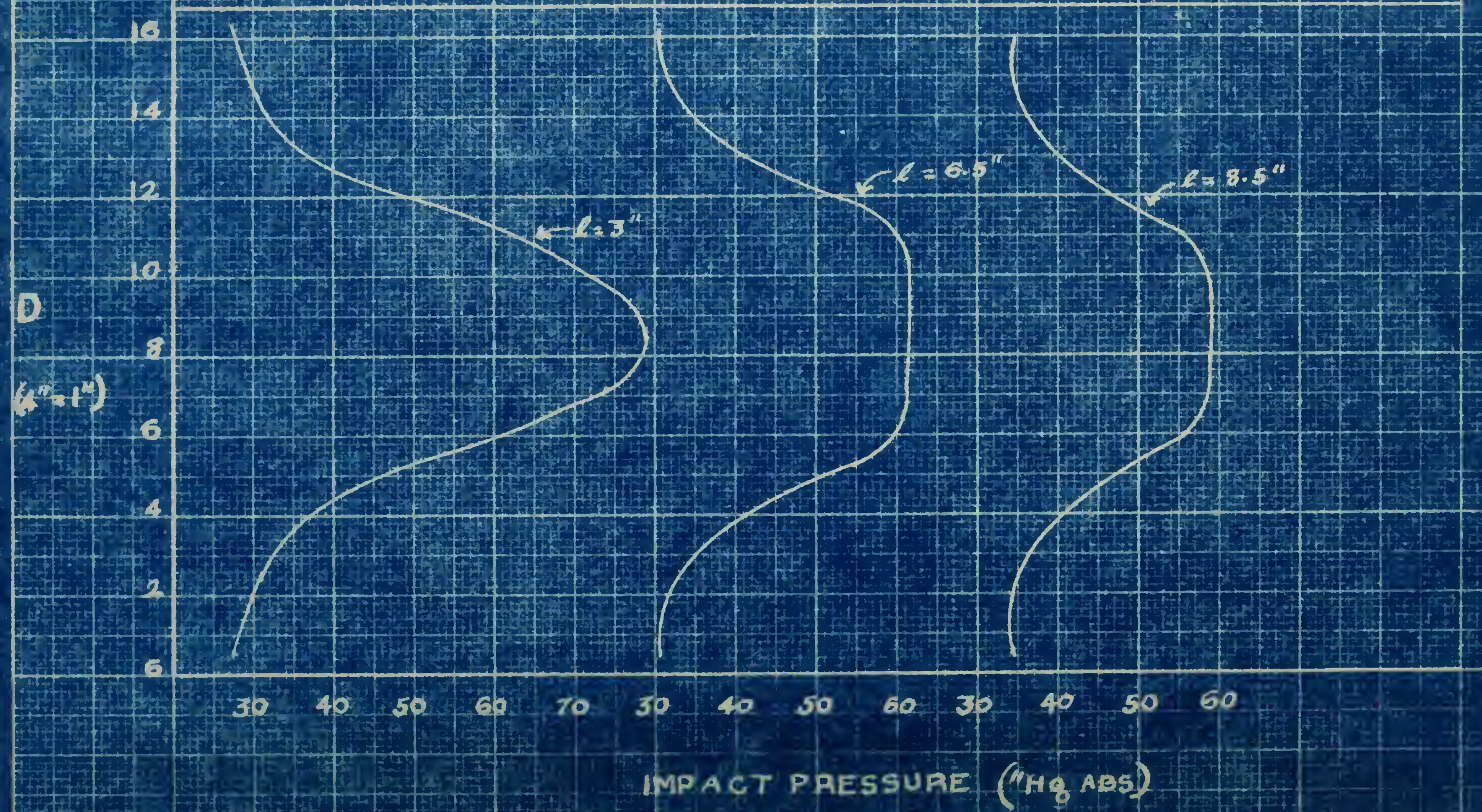


FIG. 6

MIXING TUBE DIAMETER vs IMPACT PRESSURE

SEE TABLE IV

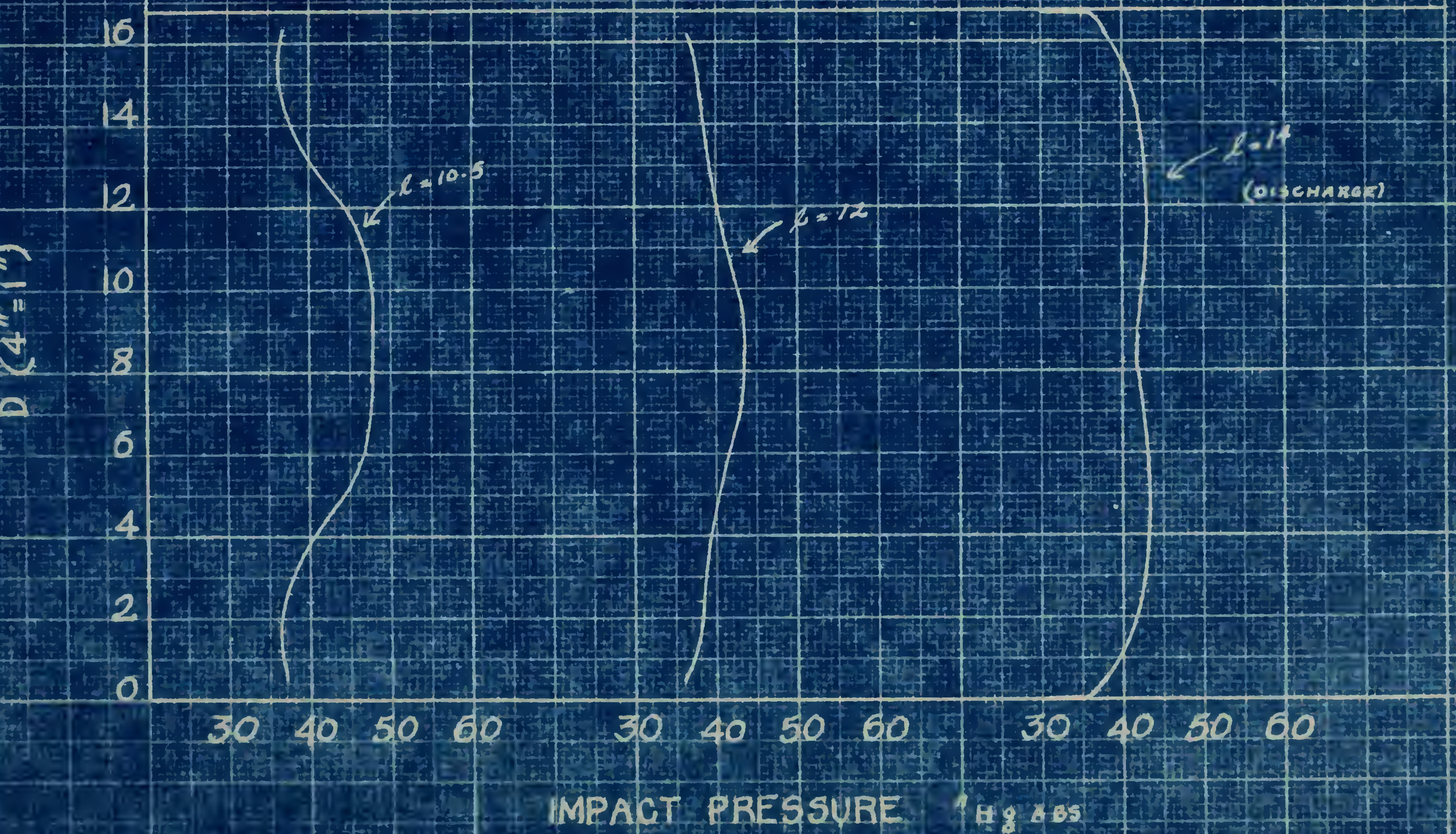
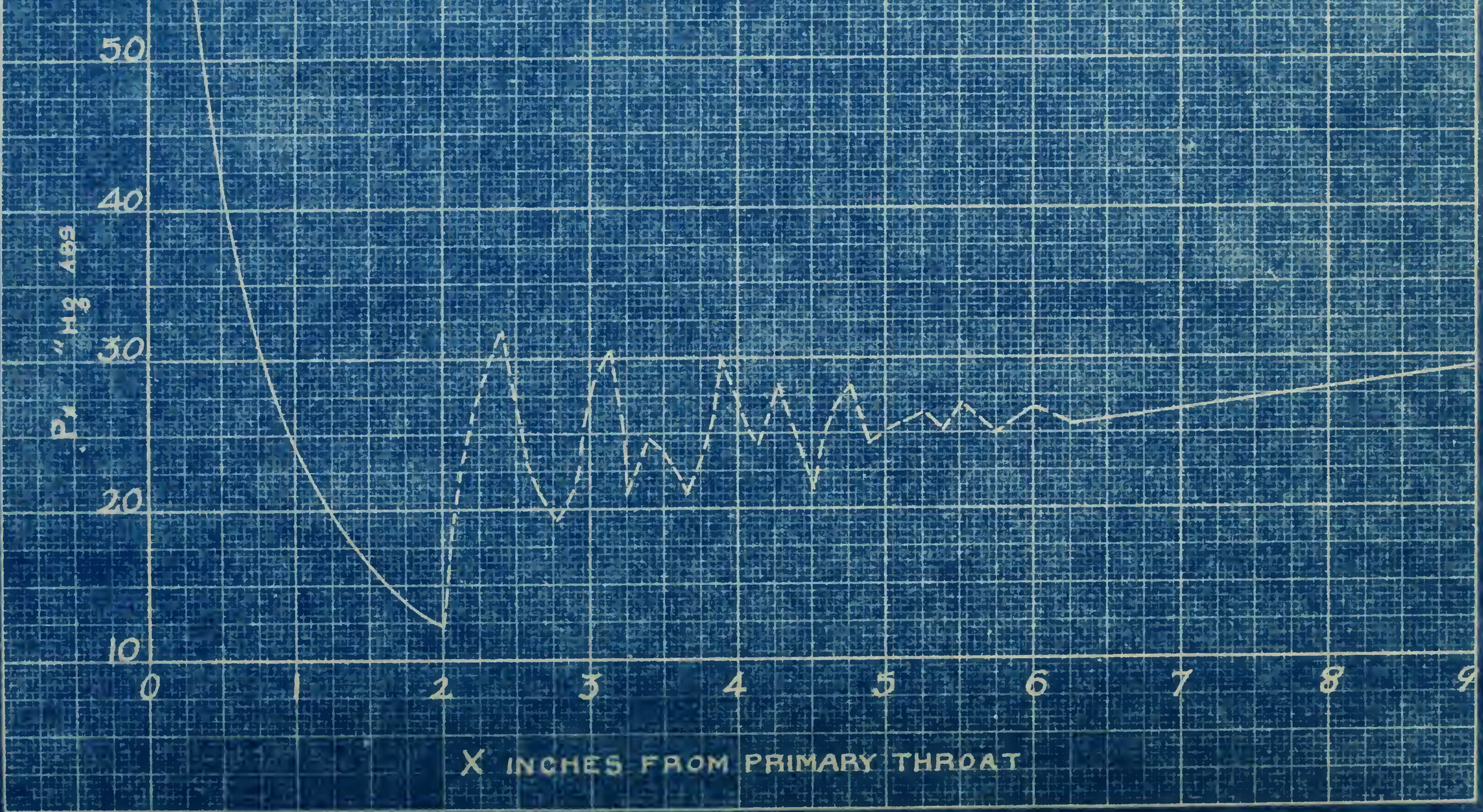


FIG. 7

STATIC PRESSURE vs X

(L=15.75"; 10" DIAMETER TRAVERSE AT l=15.75")

SEE TABLE V



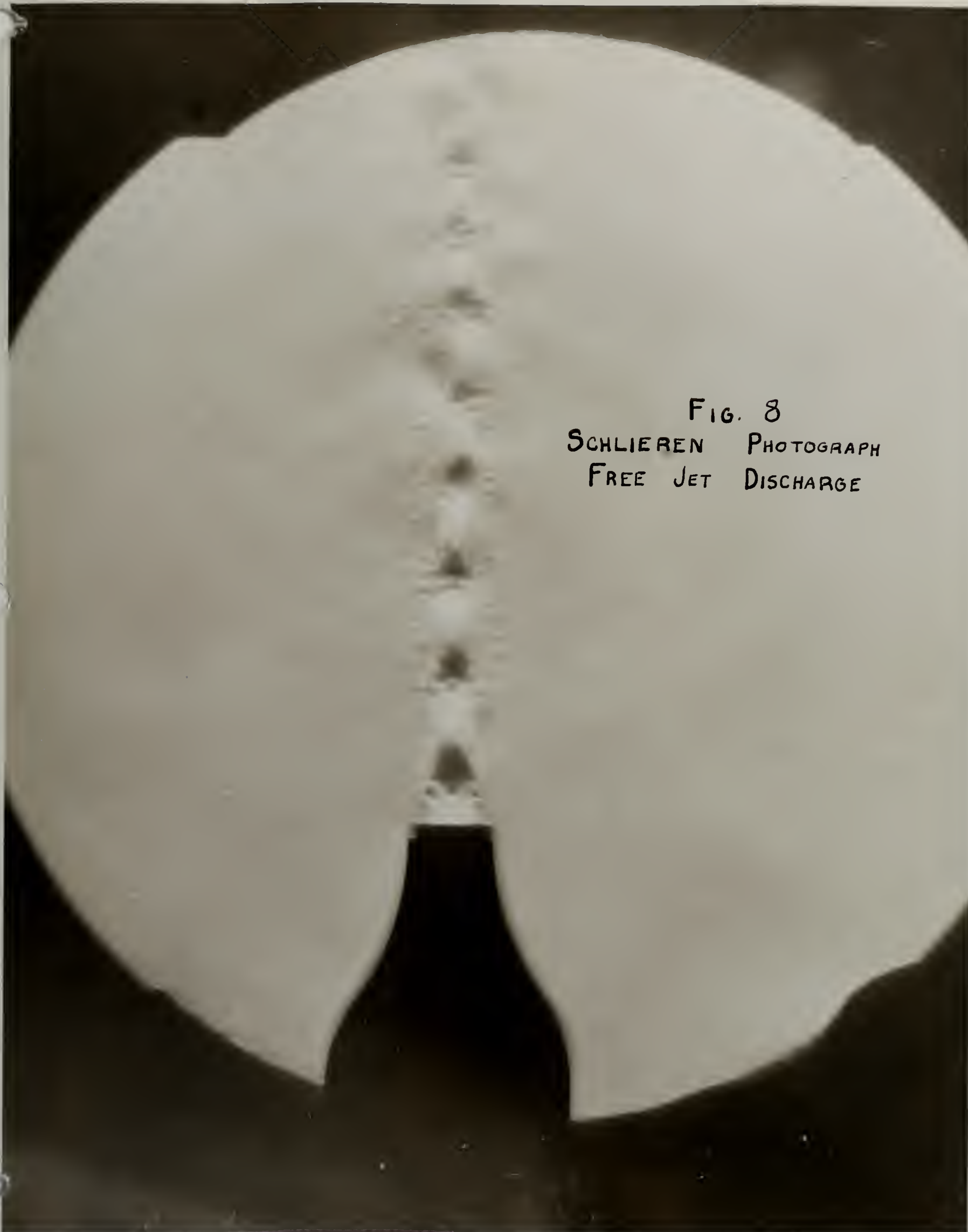


Fig. 8
Schlieren Photograph
Free Jet Discharge

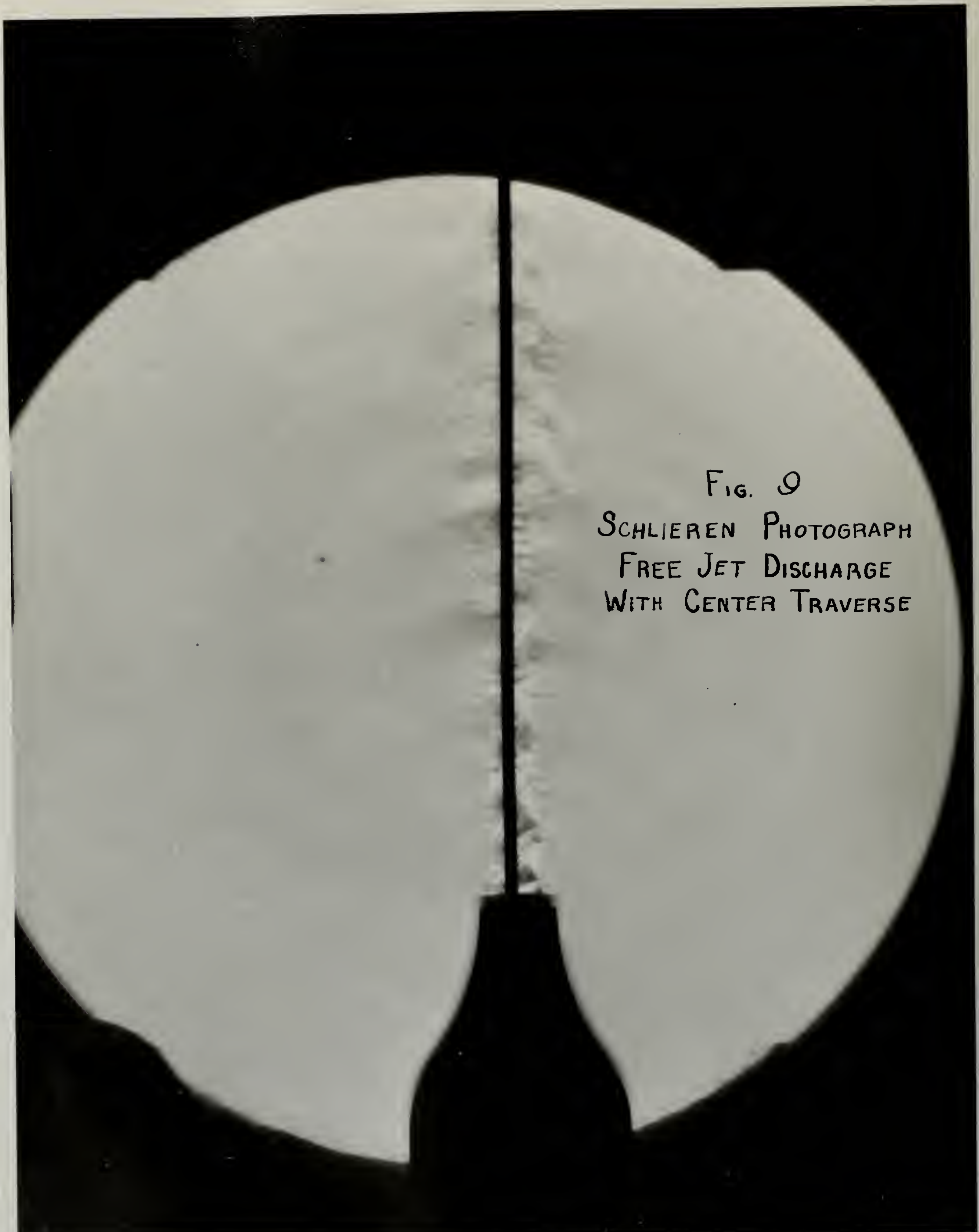


Fig. 9
Schlieren Photograph
Free Jet Discharge
With Center Traverse

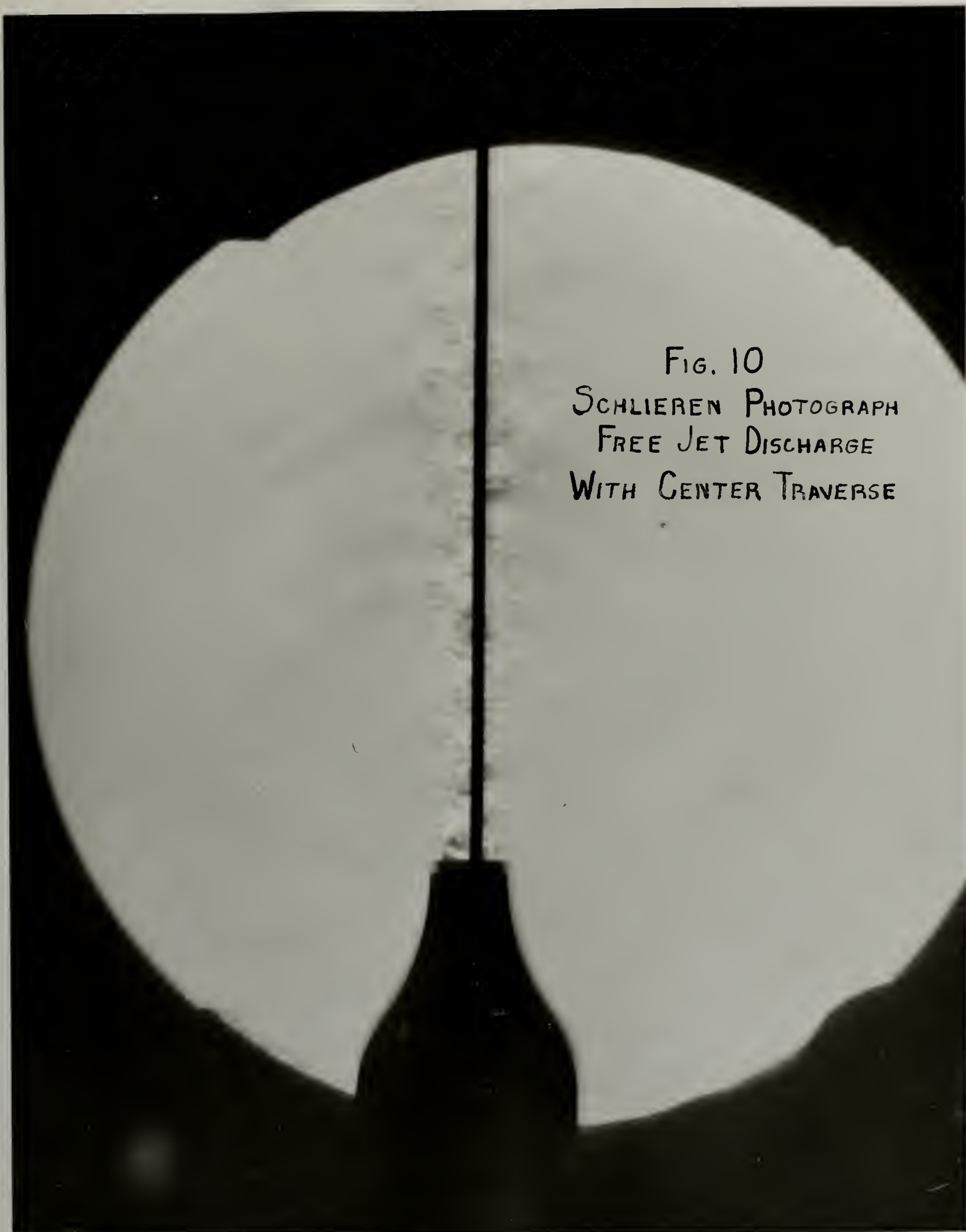


Fig. 10
Schlieren Photograph
Free Jet Discharge
With Center Traverse

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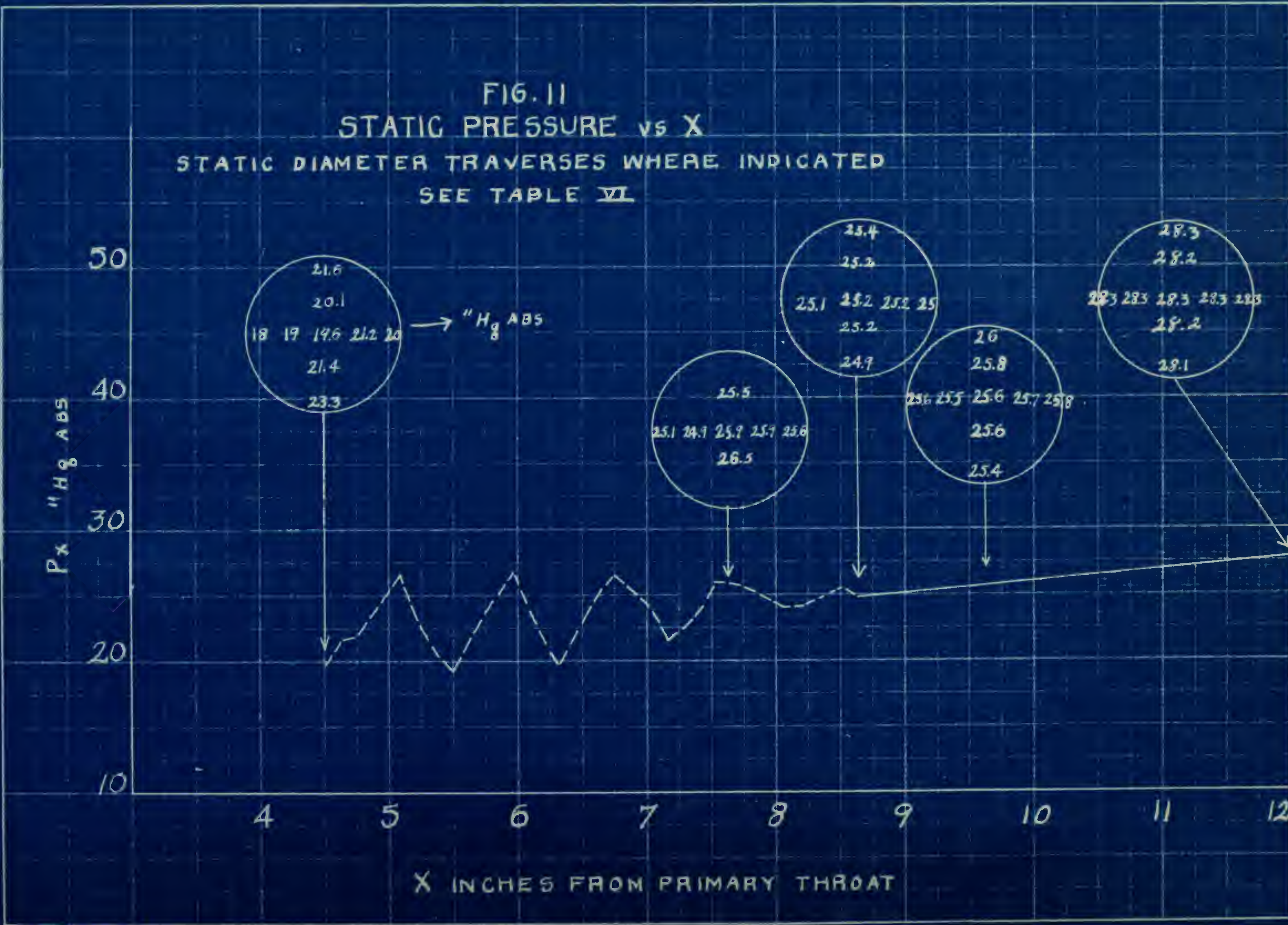


FIG. 11
STATIC PRESSURE vs X
STATIC DIAMETER TRAVERSES WHERE INDICATED
SEE TABLE VI

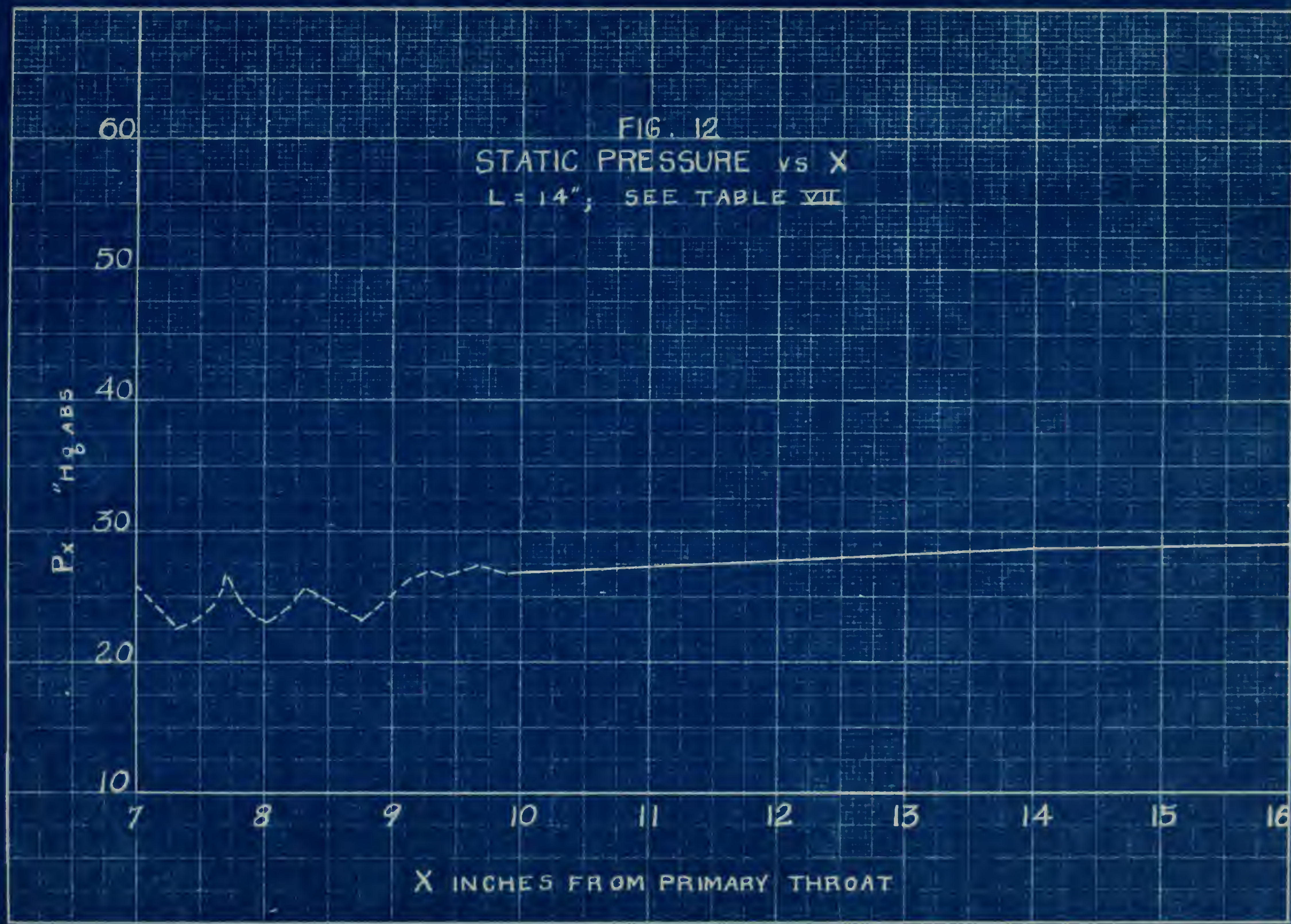
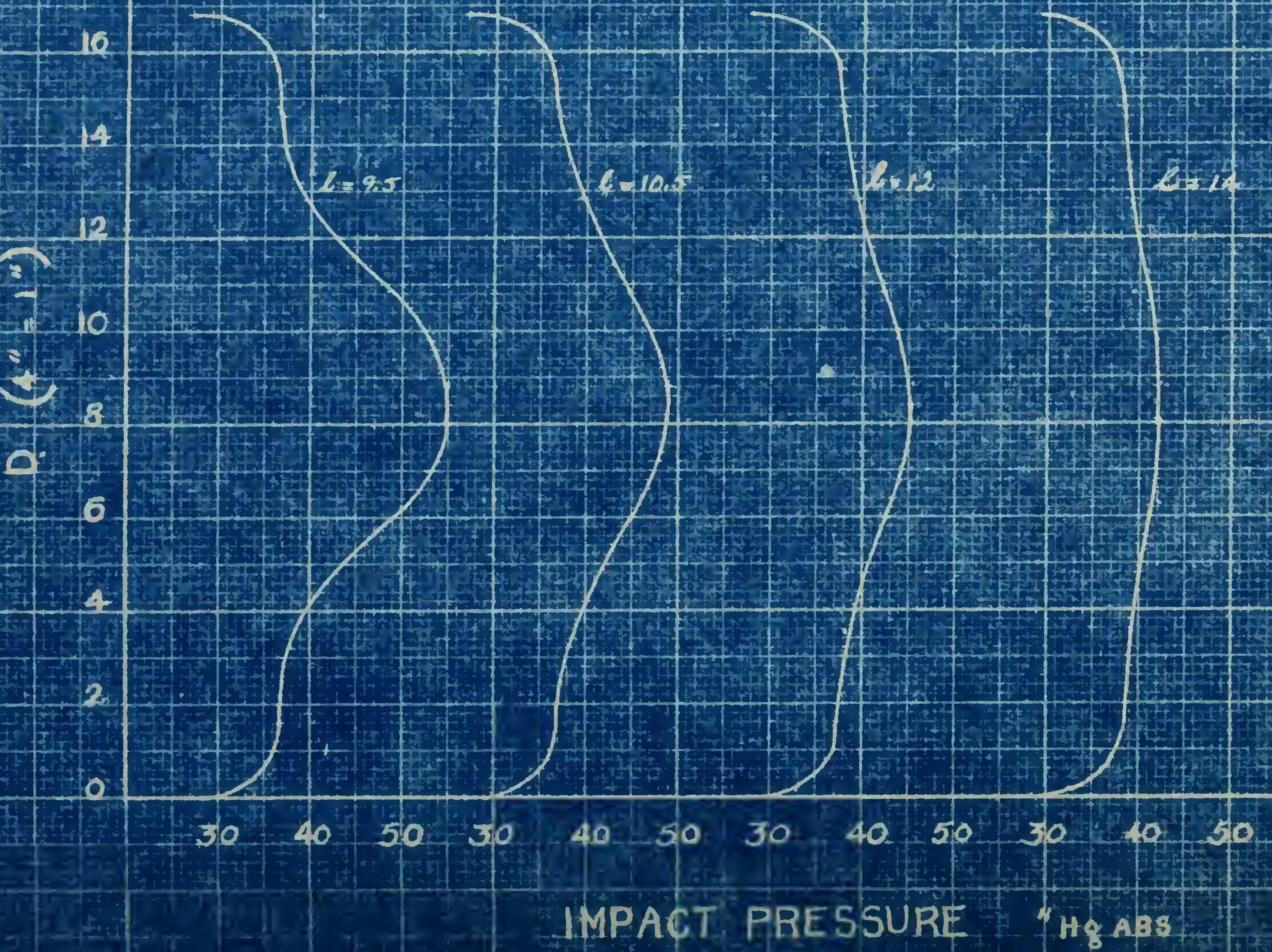


FIG. 12
STATIC PRESSURE vs X
L = 14"; SEE TABLE VII
60
50
40
30
20
10
Px "Hg ABS
7
8
9
10
11
12
13
14
15
16
X INCHES FROM PRIMARY THROAT

FIG. 13

MIXING TUBE DIAMETER vs IMPACT PRESSURE

L = 14", SEE TABLE VII



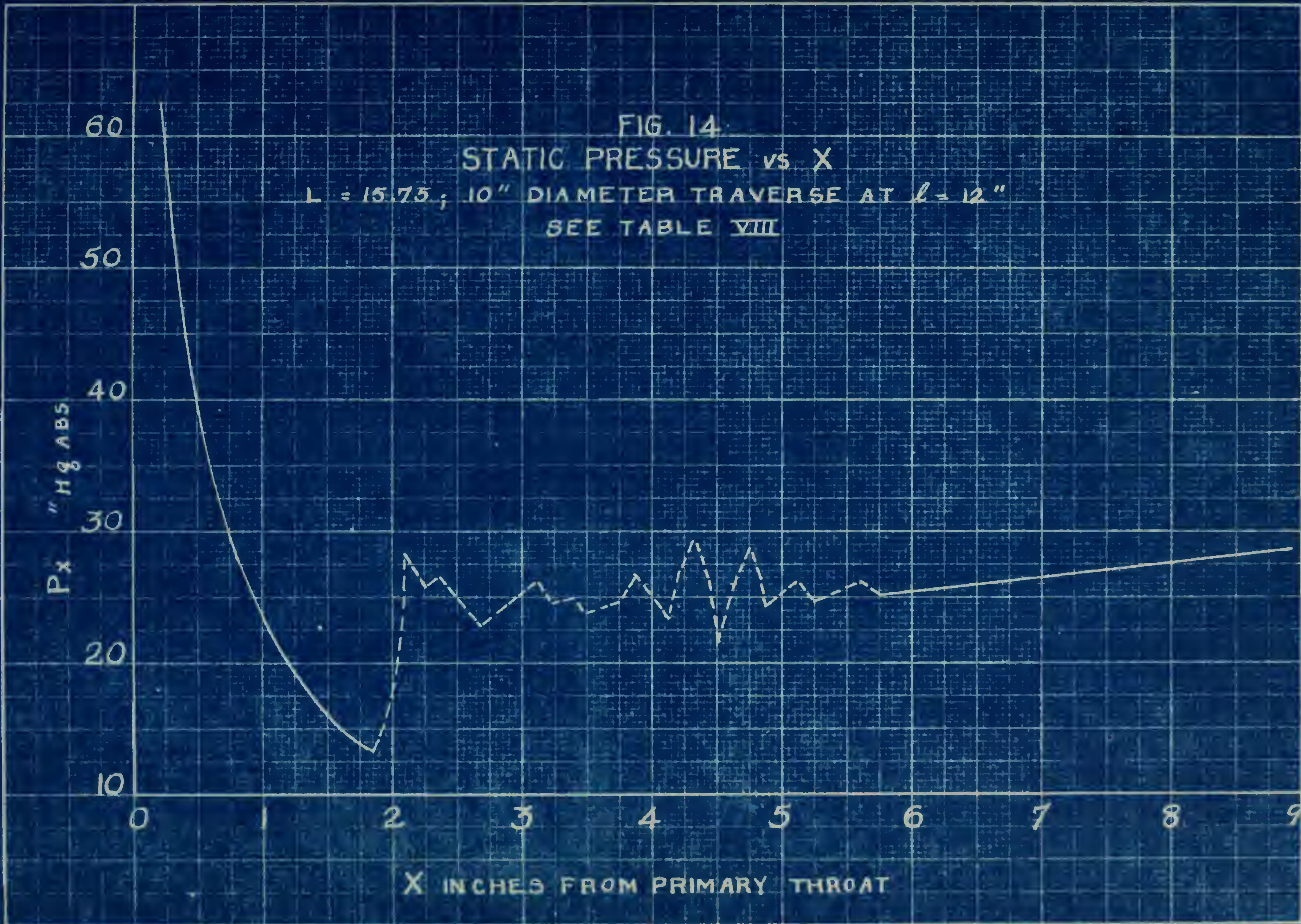


FIG. 14
STATIC PRESSURE vs X
L = 15.75 ; 10" DIAMETER TRAVERSE AT l = 12"
SEE TABLE VIII
60
50
40
30
20
10
Px "Hg ABS
0
1
2
3
4
5
6
7
8
9
X INCHES FROM PRIMARY THROAT

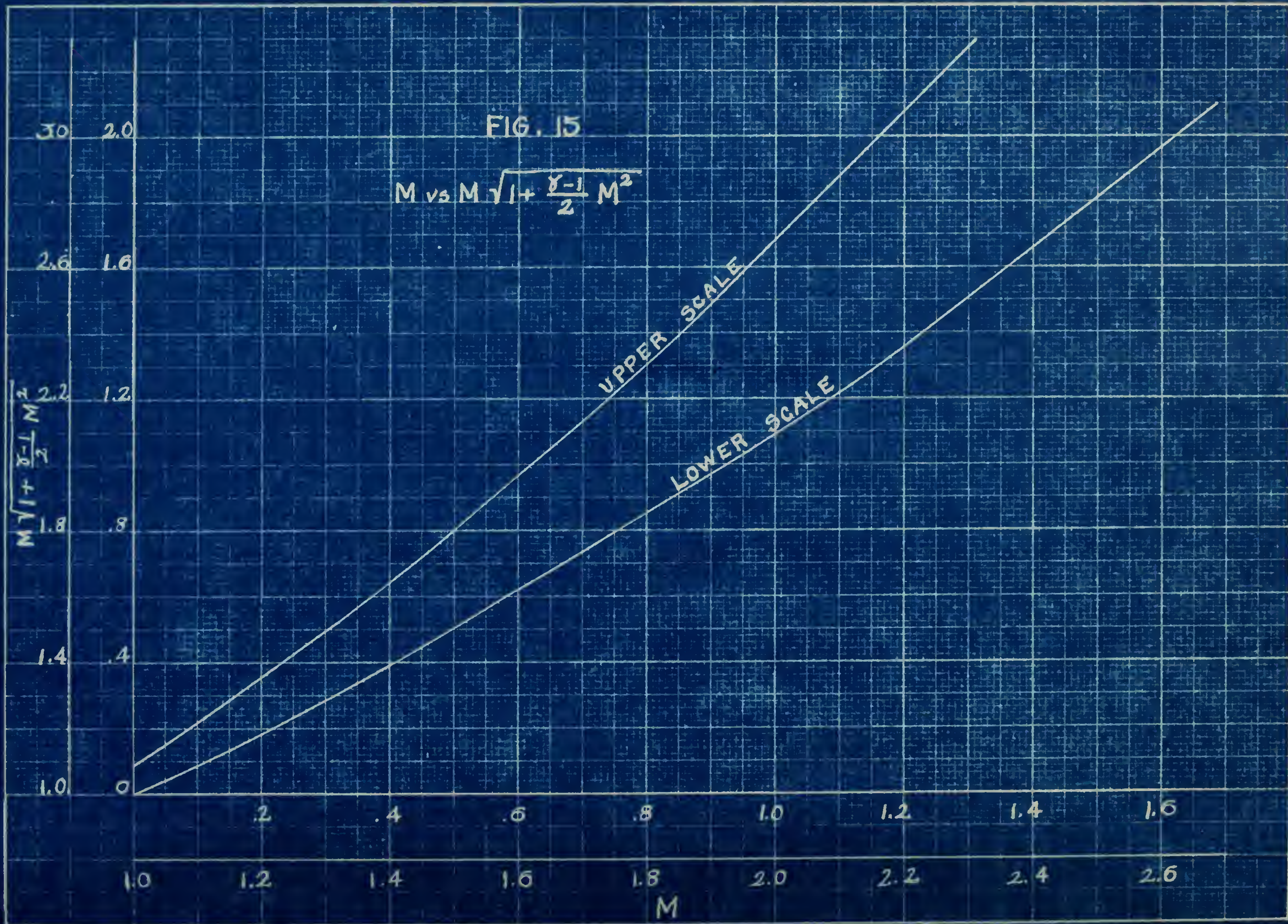


FIG. 15
M vs $M\sqrt{1+\frac{\gamma-1}{2}M^2}$
UPPER SCALE
LOWER SCALE
$M\sqrt{1+\frac{\gamma-1}{2}M^2}$
M
3.0
2.6
2.2
1.8
1.4
1.0
2.0
1.6
1.2
.8
.4
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6

FIG. 16

M vs $(1+\gamma M^2)$

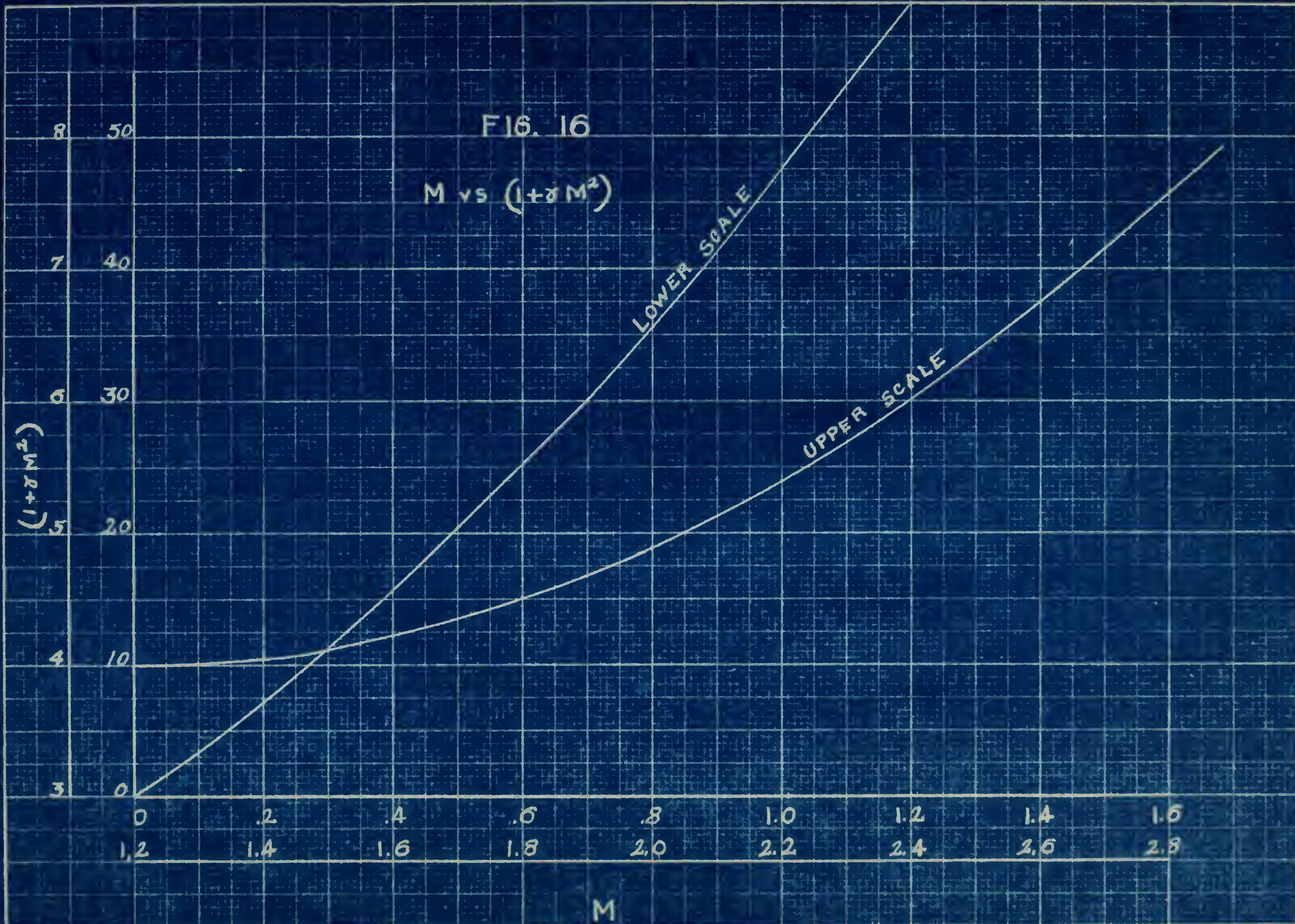
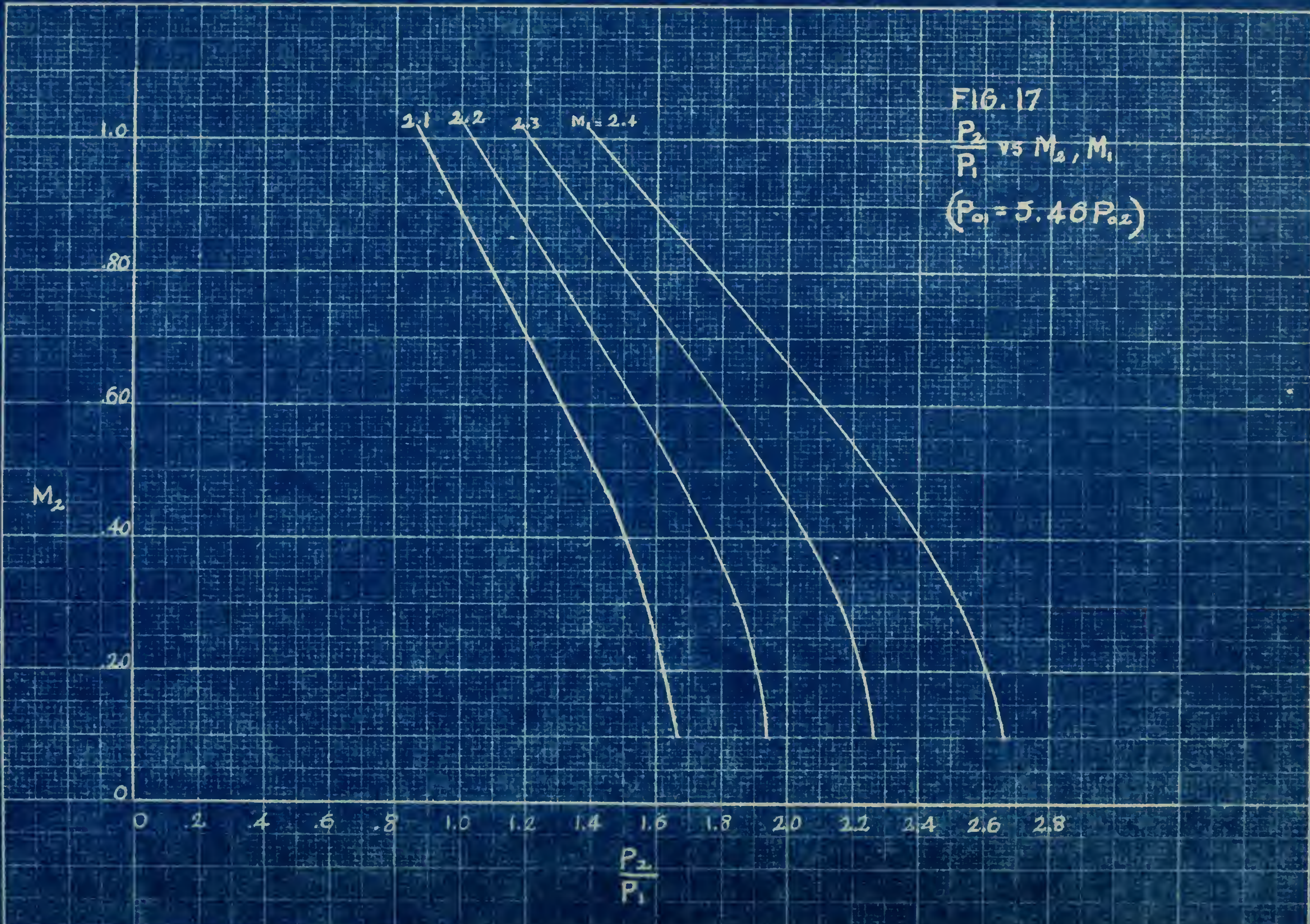


FIG. 17

$\frac{P_2}{P_1}$ vs M_2, M_1

$(P_{01} = 5.46\,P_{02})$



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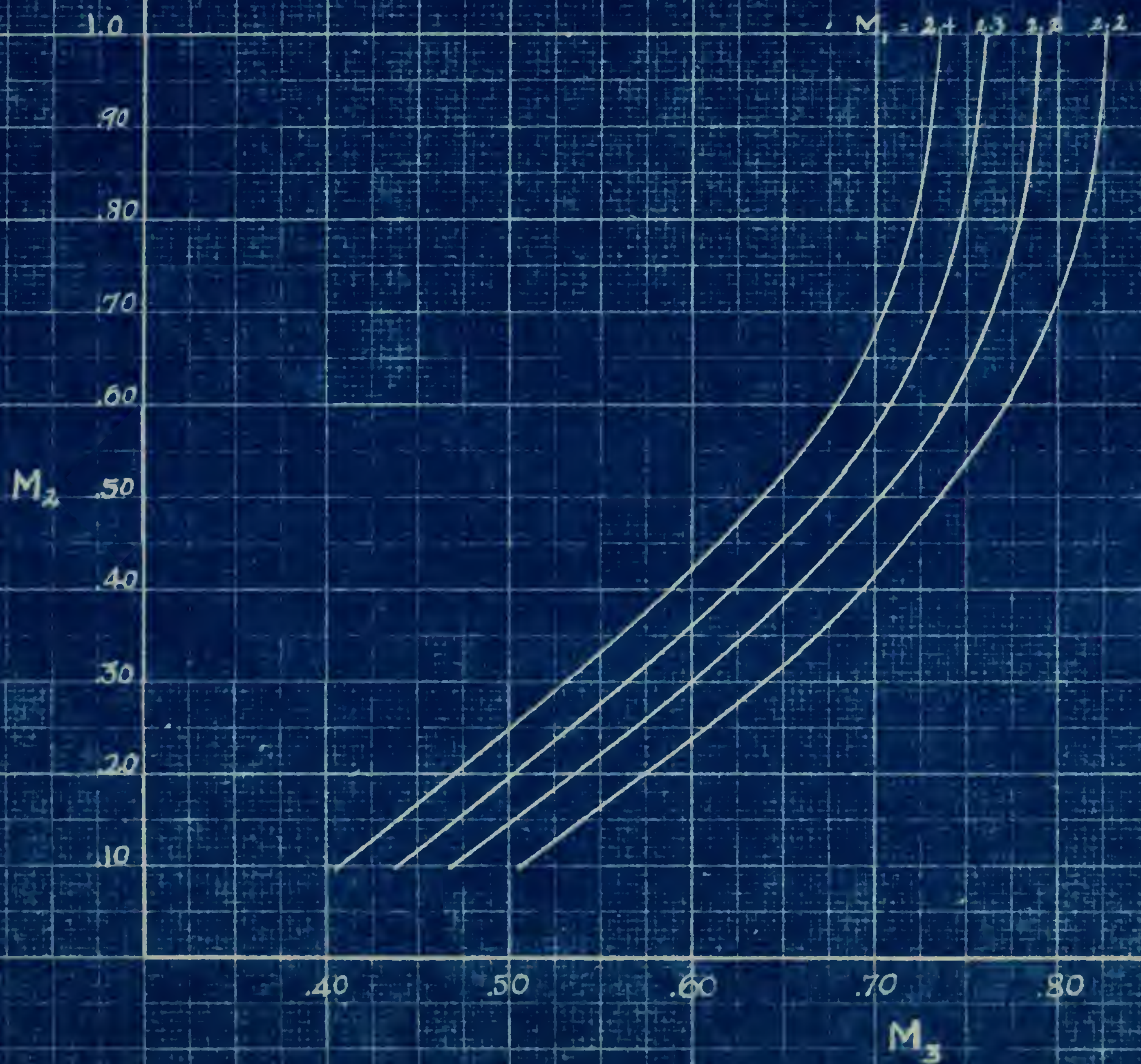

FIG. 18

M_2 vs M_3
for various M_1's
($P_{01} = 5.46\ P_{02}$)

FIG. 19

$\frac{f\gamma l}{2m}$ vs. M_2

$(P_{01} = 5.46\ P_{02})$

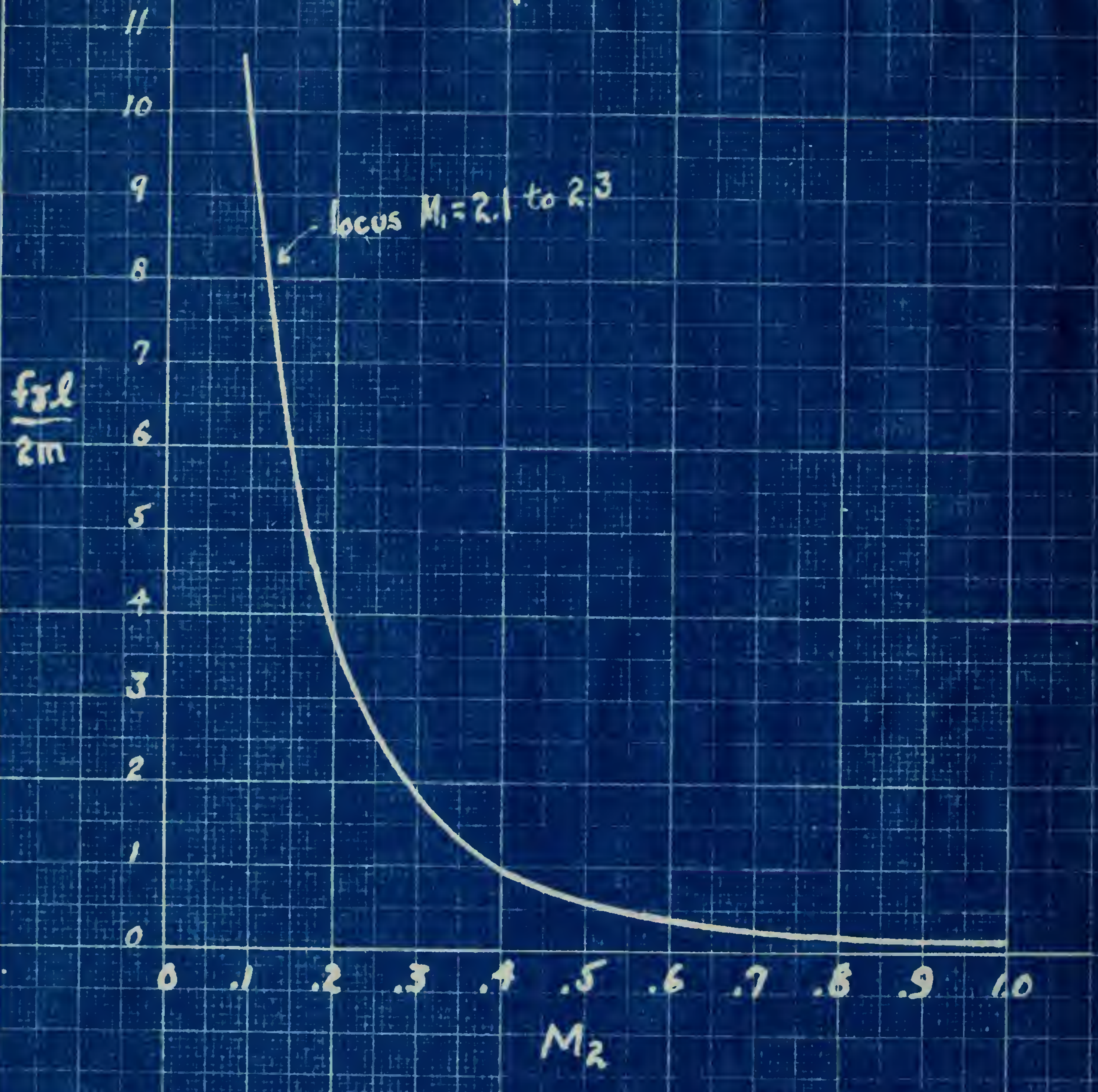

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FIG. 20

STATIC PRESSURE vs X

SURVEY OF FREE JET DISCHARGE

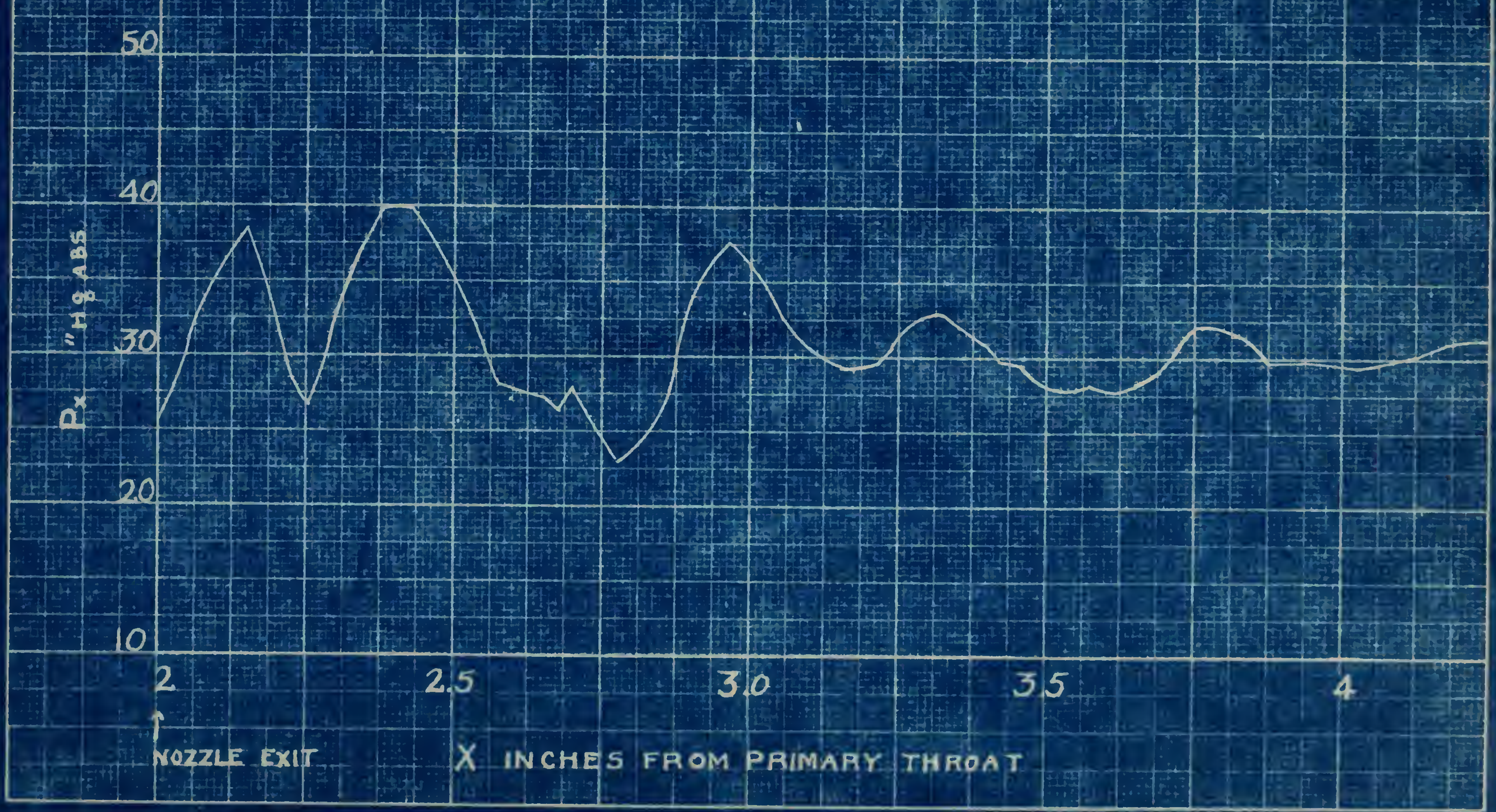

FIG. 21

DEVELOPEMENT OF THE VELOCITY PROFILE IN THE MIXING TUBE

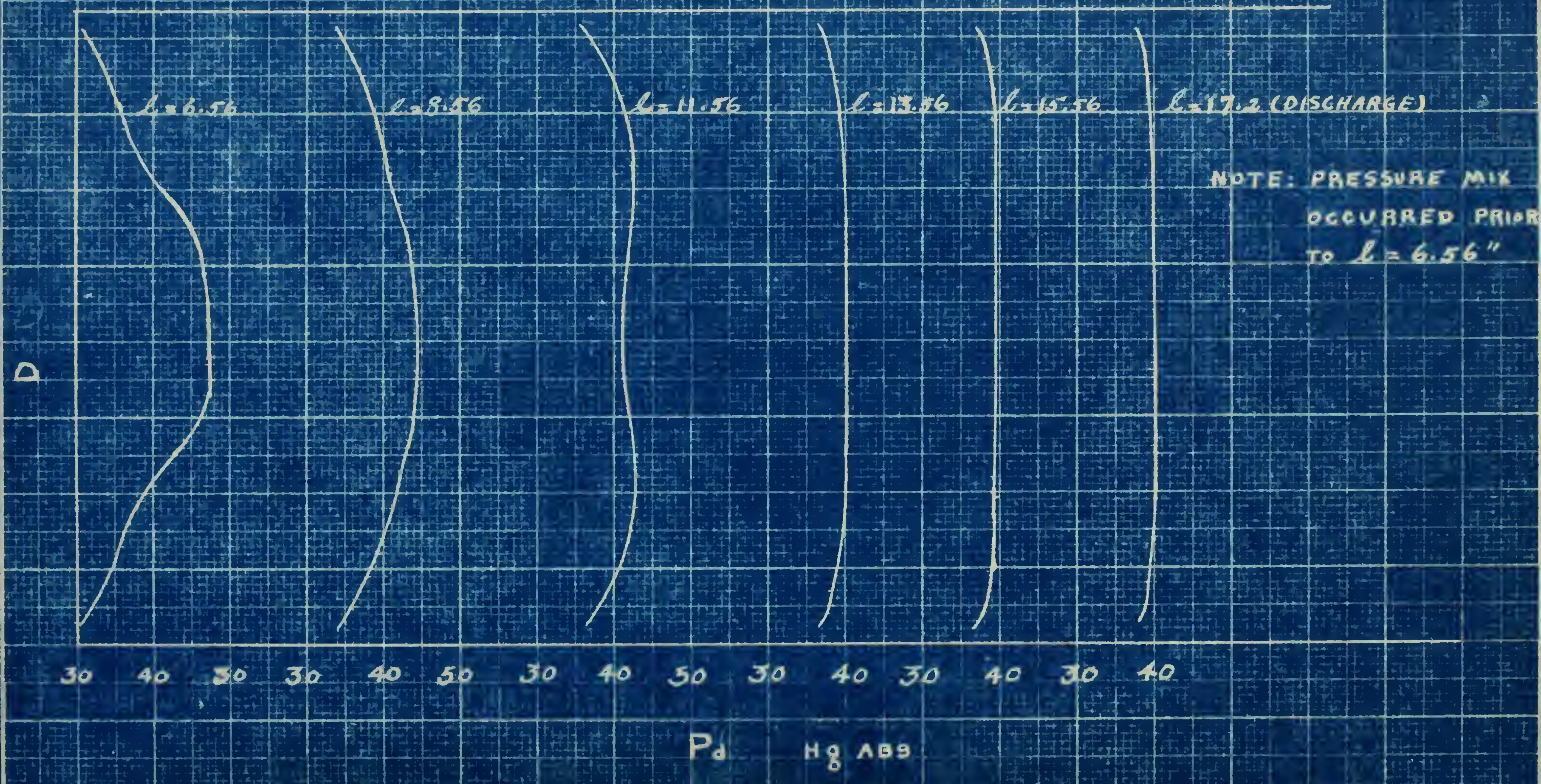

TABLE I

CALIBRATION OF SECONDARY THROAT

$_A\Delta P_B$	P_B	P_2	T_o	$\Delta P_{ORIFICE}$	$P_{1\,ORIFICE}$	COMPUTED C_V	P_{02}/P_2	
"H_2O	Psi GAGE	"HG	°F	"H_2O	"H_2O			
26	66.5	-6.8	84	.9	.49	102.6	1.273	
26.5	69	-7.0	87	.95	.53	102.2	1.282	Baro-
26.1	66.3	-6.8	90	.90	.52	101.3	1.272	meter
25.0	63.8	-6.5	90	.84	.48	100	1.26	31.6
26.3	69.5	-7.1	93	.97	.53	104.4	1.29	"Hg
25.3	66.2	-6.5	90	.9	.5	101.8	1.275	Baro-
20.3	50	-4.6	90	.75	.4	112.2	1.18	meter
25.2	67	-6.7	97	.864	.5	98	1.285	30.22
								"Hg
26.7	68	-6.9	85	.93	.51	101.1	1.306	
26.9	67.5	-6.8	86	.93	.52	101.6	1.30	
24.3	64	-6.5	92	.85	.50	98.4	1.282	Baro-
22.9	60	-6.1	93	.80	.45	100.1	1.26	meter
20.6	54	-5.4	94	.70	.40	103.3	1.225	29.5
19.5	50	-5.1	94	.68	.35	106	1.21	"Hg
17.1	41	-4.0	96	.55	.27	109	1.155	

See Page 1 of Sample Calculations

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TABLE II

CENTER TRAVERSE - L = 14"

X	P_{B1}	P_2	P_x	$_A\Delta P_B$	T_o	P_x
	Psi Gage	"Hg	"Hg	"H_2O	°F	"Hg Abs.
0	61	-7.2		22	95	
2	"	"	+54.2	"	"	83.9
4	"	"	21.1	"	"	50.8
6	"	"	7.1	"	"	36.82
8	"	"	- 2.2	"	"	27.52
10	"	"	- 8.8	"	"	20.92
12	"	"	12.5	"	"	17.22
14	"	"	14.9	"	"	14.62
16	"	"	17.3	"	"	12.42
17	61.5	-7.15	10.8	"	"	18.92
18	"	"	1.9	"	"	27.82
19	"	"	3.6	"	"	26.12
20	62	"	2.4	"	"	27.32
21	63	"	5.8	23.2	92	23.92
22	"	"	7.0	"	"	22.92
23	"	"	6.5	24	"	23.22
24	"	"	5.7	"	"	24.02
25	"	"	2.7	"	"	27.02
26	"	-7.0	5.2	"	"	24.52
27	"	"	6.0	"	"	23.92
28	"	"	5.4	"	"	24.32
29	"	"	6.2	"	120	23.72
30	"	-7.1	6.0	"	"	23.92
31	"	"	6.2	"	"	23.92
32	"	"	3.5	"	118	26.42
33	"	"	4.8	"	"	24.92
34	62	"	5.6	23.6	116	24.12
35	"	"	6.0	"	"	23.92
36	"	"	5.9	"	"	23.82
37	"	"	4.9	"	110	24.82
38	61.5	"	4.0	"	"	25.92
39	"	"	5.2	"	"	24.52
40	"	"	5.8	"	104	23.92
41	61	"	5.8	23.8	"	23.92
42	"	"	4.9	"	"	24.82
43	"	"	4.2	"	"	25.52
44	"	"	5.0	"	"	24.92

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TABLE II (Cont.)

CENTER TRAVERSE - L = 14"

X	P_{B1}	P_2	P_X	$_A\Delta P_B$	T_o	P_X
	Psi Gage	"Hg	"Hg	"H_2O	°F	"Hg Abs.
45	61	-7.1	-5.4	23.9	104	24.52
46	"	"	-5.5	"	"	24.42
47	"	"	5.2	"	"	24.72
48	"	"	4.4	"	"	25.32
49	"	"	4.3	"	100	25.62
50	"	"	5.0	"	"	24.92
51	"	"	5.4	"	"	24.52
52	"	"	4.7	"	"	25.22
53	"	"	4.3	"	"	25.62
54	"	"	4.3	"	"	25.62
55	"	"	4.6	"	"	25.12
56	"	"	4.8	"	"	24.92
57	"	"	4.4	"	"	25.52
58	"	"	3.8	"	"	25.12
59	"	"	3.8	"	"	25.12
60	"	"	4.0	"	"	25.92
61	"	"	4.0	"	"	25.95
62	"	"	3.5	"	"	26.42
63	"	"	3.3	"	"	26.62
64	"	"	3.5	"	"	26.42
65	"	"	3.5	"	"	26.42
66	"	"	2.9	"	"	27.02
67	"	"	2.8	"	"	27.12
68	"	"	2.6	"	"	27.32
69	"	"	2.6	"	"	27.32
70	"	"	2.3	"	"	27.62
71	"	"	2.0	"	"	27.92

Barometer = 29.72 "Hg = 14.61 psi = 2105 psf

W_1 = .1652 #/sec $\quad$ W_2 = .178 #/sec

To_1 = 100 $\quad$ To_2 = 80

M_1 = 2.238 $\quad$ M_2 = .647

$_A\Delta P_B$ = 124 $\quad$ P_2 = 22.62 "Hg abs

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TABLE III

CENTER TRAVERSE - L = 15.75"

X	P_x "Hg Gage	P_x "Hg Abs.
0	63.5	92.3
1	39.3	68.1
2	29.8	58.6
3	19.7	48.5
4	12.3	41.1
5	6.4	35.2
6	1.3	30.1
7	- 2.7	26.1
8	- 5.6	23.2
9	--7.8	21.0
10	- 9.4	19.4
11	-11.2	17.6
12	-12.8	16.0
13	-14.1	14.7
14	-15.2	13.6
15	-16.6	12.2
16	-17.2	11.6
17	- 5.2	23.6
18	- 3.8	25.0
19	- .5	28.3
20	- 2.5	26.3
21	- 8.8	20.0
22	- 9.3	19.5
23	- 9.0	19.8
24	- 7.5	21.3
25	- .6	28.2
26	- 4.4	24.4
27	- 7.4	21.4
28	- 3.6	25.2
29	- 8.5	20.3
30	- 8.1	20.7
31	- 6.6	22.2
32	- 2.6	26.2
33	- 7.0	21.8
34	- 7.5	21.3
35	- 3.9	24.9
36	- 1.8	27
37	- 6.7	22.1
38	- 6.7	22.1
39	- 3.0	25.8
40	- 3.8	25.0
41	- 6.4	22.4
42	- 4.4	24.4
43	- 3.7	25.1
44	- 4.2	24.6
45	- 5.4	23.4
46	- 4.7	24.1
47	- 3.0	25.8
48	- 4.7	24.1
49	-4.9	23.9
50	-3.8	25.0
51	-4.3	24.5
52	-4.7	24.1
53	-4.7	24.1
54	-3.7	25.1
55	-3.8	25.0
56	-4.2	24.6
57	-4.2	24.6
58	-3.9	24.9
59	-3.9	24.9
60	-3.9	24.9
61	-3.9	24.9
62	-3.9	24.9
63	-3.5	25.2
64	-3.4	25.4
65	-3.3	25.5
66	-3.2	25.6
67	-2.8	26.0
68	-2.7	26.1
69	-2.6	26.2
70	-2.5	26.3
71	-2.3	26.5
72	-2.1	26.7

Barometer = 28.8 "Hg = 14.17 psi
= 2040 psf

${}_A\Delta P_B$ = 22.5 "H_2O = 117 psf

W_1 = .1627 #/sec

P_2 = -6.4 "Hg gage = 22.4 "Hg abs

W_2 = .1728 #/sec

To_1 = 95° F To_2 = 80° F

P_B = 63.2 psi gage = 78 psi abs

M_1 = 2.31

M_2 = .625

3-54

TABLE IV

IMPACT SURVEYS L = 14"

X	$_A\Delta P_B$	P_B	T_o	P_2	P_X	P_{WALL}
	"H_2O	Psi Gage	°F	"Hg	"Hg	
14	23.3	65	95	-7.0	-16.2	
16					-18.2	
17					.3	
18					- 4.9	
19					- 4.8	
20					- 5.1	-7.1
21					- 7.5	
22					- 8.3	
32					- 3.7	- 4.5
33					- 4.9	
40					- 4.2	-5.5
41					- 6.4	
48					- 7.5	-5.9
49					- 7.1	
56					- 6.0	-5.6
57					- 4.6	
68					- 4.8	-5.2
69					- 4.2	

IMPACT SURVEYS:

	d	Pd		Pd		Pd
		"Hg Abs.		"Hg Abs.		"Hg Abs.
At l=3"	1/32	27.8	At l=6.5"	30.7	At l=8.5"	34.4
	1/8	29.8		31.4		33.9
	2/8	36.3		41.5		39.9
	3/8	62.5		61.5		55.9
	4/8	79.8		57.9		58.9
At l=10.5"	1/32	37.1	At l=12"	36.2	At l=14"	37.9
	1/8	36		38		41.1
	2/8	40.1		39.7		43.2
	3/8	47		41.3		43.3
	4/8	48		44.1		42

Barometer = 29.9 "Hg = 14.7 psi = 2116 psf

W_1 = .1682 #/sec M_1 = 2.35

W_2 = .1813 #/sec M_2 = .638

To_1 = 95°F To_2 = 75°F

3-55

TABLE V

CENTER TRAVERSE -.10" DIAMETER TRAVERSE AT 15.75"

X	P_x "Hg Gage	P_x "Hg Abs.	X	P_x "Hg Gage	P_x "Hg Abs.
0	62.6	91.4	49	2.7	26.1
1	41.6	70.4	50	3.3	25.5
2	29.5	58.3	51	2.9	25.9
3	19.9	48.7	52	2.6	26.2
4	12.1	40.9	53	2.7	26.1
5	6.6	35.4	54	2.4	26.4
6	1.6	30.4	55	2.2	26.6
7	- 2.2	26.6	56	2.0	26.6
8	- 5.2	23.6	57	1.9	26.8
9	7.6	21.2	58	1.4	26.8
10	9.2	19.6	59	1.3	26.9
11	11.2	17.6	60	1.2	27.4
12	12.7	16.1	61	1.0	27.5
13	14.3	14.5	62	.9	27.6
14	15.3	13.5	63	.7	28.0
15	16.5	12.3	64	.5	27.9
16	16.6	12.2	65	.3	28.1
17	5.1	23.7	66	0	28.3
18	1.2	27.6	67	+ .1	28.5
19	+ 2.8	31.6	68	.3	28.8
20	- 2.7	26.1	69	.4	28.9
21	8.9	19.9	70	.4	29.1
22	9.7	19.1	71	.5	29.2
23	8.5	20.3	72	.55	29.3
24	.6	28.2			
25	+ 1.7	30.5			
26	- 7.6	21.2			
27	- 4.2	24.6			
28	5.4	23.4			
29	8.0	20.8			
30	6.0	22.8			
31	+ 1.7	30.5			
32	- 2.7	26.1			
33	4.8	24.0			
34	.6	28.2			
35	3.9	24.9			
36	7.7	21.1			
37	2.2	26.6			
38	.8	28.0			
39	4.6	24.2			
40	3.7	25.1			
41	2.8	26.0			
42	2.7	26.1			
43	3.7	25.1			
44	1.6	27.2			
45	3.0	25.8			
46	4.0	24.8			
47	2.6	26.2			
48	2.2	26.6			

Barometer = 28.8 "Hg = 14.17 psi
= 2040 psf

$_A\Delta P_B$ = 22.6 "H_2O = 117 psf

W_1 = .1630 #/sec

To_1 = 97°F To_2 = 80°F

P_2 = -4.9 "Hg gage = 23.9 "Hg abs

W_2 = .1638 #/sec

P_B = 63.5 psi abs

M_1 = 2.25

M_2 = .558

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TABLE VI

STATIC PRESSURE SURVEY

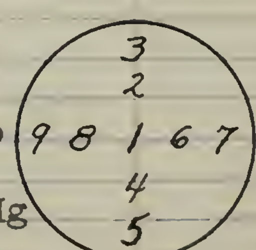
NO CENTERLINE TRAVERSE L = 14"

l	d	P_x "Hg Gage	P_x "Hg Abs.
2.5	1	-10.2	19.61
	2	- 9.7	20.11
	3	- 8.2	21.61
	4	- 8.4	21.41
	5	- 6.5	23.31
	6	- 8.6	21.21
	7	- 9.8	20.01
	8	-10.8	19.01
	9	-11.8	18.01
5 5/8	1	- 3.9	25.91
	2	- 4.3	25.51
	3		
	4	- 3.3	26.51
	5		
	6	- 3.9	25.91
	7	- 4.2	25.61
	8	- 4.9	24.91
	9	- 4.7	25.11
6 5/8	1	- 4.6	25.21
	2	- 4.6	25.21
	3	- 4.4	25.41
	4	- 4.6	25.21
	5	- 4.9	24.91
	6	- 4.6	25.21
	7	- 4.8	25.01
	8	- 4.7	25.11
	9	- 4.9	24.91
7 5/8	1	- 4.2	25.61
	2	- 4.0	25.81
	3	- 3.8	26.01
	4	- 4.2	25.61
	5	- 4.4	25.41
	6	- 4.1	25.71
	7	- 4.0	25.81
	8	- 4.3	25.51
	9	- 4.2	25.61
10	1	- 1.5	28.31
	2	- 1.6	28.21
	3	- 1.5	28.31
	4	- 1.6	28.21
	5	- 1.7	28.11
	6	- 1.55	28.26
	7	- 1.55	28.26
	8	- 1.5	28.31
	9	- 1.5	28.31

Survey For "Damp Out"

X	P_x "Hg Gage	P_x "Hg Abs
36	-10.3	19.51
37	- 8.3	21.61
38	- 7.9	21.91
39	- 6.1	23.71
40	- 4.4	25.41
41	- 4.2	25.61
42	- 6.8	23.01
43	- 9.6	20.21
44	-10.6	19.21
45	- 7.9	21.91
46	- 6.0	23.81
47	- 4.2	25.61
48	- 4.0	25.81
49	- 7.1	22.71
50	- 9.2	20.61
51	- 9.0	20.81
52	- 7.0	22.81
53	- 4.4	25.41
54	- 3.3	26.51
55	- 4.6	25.21
56	- 5.7	24.11
57	- 8.0	21.81
58	- 7.5	22.31
59	- 6.4	23.41
60	- 4.3	25.51
61	- 3.9	25.91
62	- 4.3	25.51
63	- 5.0	24.81
64	- 5.7	24.11
65	- 5.8	24.01
66	- 5.5	24.31
67	- 4.08	25.01
68	- 4.4	25.41
69	- 4.6	24.91
70	- 4.7	25.11
71	- 4.7	25.11
72	- 4.6	25.21
73	- 4.4	25.41
74	- 4.2	25.61
75	- 4.2	25.61
76	- 4.2	25.61

"d" nomenclature



Barometer =
29.81 "Hg

TABLE VII

CENTER TRAVERSE, ENTIRE LENGTH,
PLUS IMPACT SURVEYS L=14"

X	$_A\Delta P_B$	P_2	P_x	T_o	P_B	P_x
	"H_2O	"Hg	"Hg	°F	Psi Gage	"Hg Abs.
14	23.3	-5.8	-16.1	92	64	12.7
16			-17.8			11.0
17			- 0.1			28.7
18			- 4.4			24.4
56	23.3	-5.9	- 3.6	96	64.5	25.2
57	"	"	- 4.1	"	"	24.7
58	"	"	- 5.8	"	"	23.0
59	"	"	- 6.0	"	"	22.8
60	"	"	- 5.2	"	"	23.6
61	"	"	- 3.8	"	"	25.0
62	"	"	- 3.6	"	"	25.2
63	"	"	- 4.8	"	"	24.0
64	"	"	- 5.6	"	"	23.2
65	"	"	- 5.0	"	"	23.8
66	"	"	- 3.6	"	"	25.2
67	"	"	- 3.8	"	"	25.0
68	"	"	- 4.8	"	"	24.0
69	"	"	- 5.0	"	"	23.8
70	"	"	- 5.5	"	"	23.3
71	"	"	- 4.4	"	"	24.4
72	"	"	- 3.3	"	"	25.5
73	"	"	- 2.2	"	"	26.6
74	"	"	- 1.9	"	"	26.9
75	"	"	- 2.1	"	"	26.7
76	"	"	- 1.7	"	"	27.1
77	"	"	- 1.6	"	"	27.2
78	"	"	- 1.8	"	"	27.0
79	"	"	- 2.1	"	"	26.7
80	"	"	- 2.0	"	"	26.8
81	"	"	- 2.0	"	"	26.8
82	"	"	- 1.8	"	"	27.0
83	"	"	- 1.8	"	"	27.0
84	"	"	- 1.8	"	"	27.0
85	"	"	- 1.6	"	"	27.2
86	"	"	- 1.6	"	"	27.2
87	"	"	- 1.5	"	"	27.3
88	"	"	- 1.35	"	"	27.15
89	"	"	- 1.2	"	"	27.6
90	"	"	- 1.2	"	"	27.6
91	"	"	- 1.1	"	"	27.7
92	"	"	- 1.0	"	"	27.8
93	"	"	- 1.0	"	"	27.8
94	"	"	- 1.0	"	"	27.8
95	"	"	- 1.0	"	"	27.8
96	"	"	- .95	"	"	27.85
97	"	"	- .8	"	"	28.0
98	"	"	- .8	"	"	28.0
99	"	"	- .75	"	"	28.05
100	"	"	- .6	"	"	28.2

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X	ΔP_B "H_2O	P_z "Hg	P_x "Hg	T_o °F	P_B Psi Gage	P_x "Hg Abs.
101	23.3	- 5.9	- .55	96	64.5	28.25
102	"	"	- .55	"	"	28.25
104	"	"	- .45	"	"	28.35
106	"	"	- .35	"	"	28.45
108	"	"	- .30	"	"	28.5
110	"	"	- .25	"	"	28.55
112	"	"	- .20	"	"	28.6
114	"	"	- .20	"	"	28.6
116	"	"	- .15	"	"	28.65
118	"	"	- .15	"	"	28.65
120	"	"	- .10	"	"	28.7
122	"	"	- .10	"	"	28.7
124	"	"	- .10	"	"	28.7
126	"	"	- .05	"	"	28.75
128	"	"	0	"	"	28.8

IMPACT SURVEYS

	d	Pd "Hg Gage	Pd "Hg Abs.
l = End (14")	1/32	+9.0	37.8
	1/8	9.6	38.4
	2/8	10.6	39.4
	3/8	12.4	41.2
	4/8	13.6	42.4
	5/8	13.0	41.8
l = 12"	1/32	8	36.8
	1/8	8.4	37.2
	2/8	10.6	39.4
	3/8	13.6	42.4
	4/8	16.4	45.2
	5/8	15	43.8
l = 10.5"	1/32	7.5	36.3
	1/8	8	36.8
	2/8	10.3	39.1
	3/8	16	44.8
	4/8	20.4	49.2
	5/8	19.5	48.3
l = 9.5"	1/32	6.7	35.5
	1/8	7.3	36.1
	2/8	10.6	39.4
	3/8	19.7	48.5
	4/8	28	56.8
	5/8	24	52.8

Barometer = 28.8 "Hg

M_1 = 2.41

M_2 = .592

W_1 = .164 #/sec

W_2 = .167 #/sec

To_2 = 76°F

To_1 = 96°F

P_2 = 22.9 "Hg

TABLE VIII

CENTER TRAVERSE - DIAMETER TRAVERSE
AT 1 = 12" L = 15.75

X	P_x "Hg Gage	P_x "Hg Abs	X	P_x "Hg Gage	P_x "Hg Abs.
0	62.6	91.4	49	3.5	25.3
1	36.1	64.9	50	-3.5	25.3
2	30.4	59.2	51	3.6	25.2
3	20.1	48.9	52	3.5	25.3
4	12.0	40.8	53	3.4	25.4
5	6.2	35.0	54	3.3	25.5
6	1.3	30.1	55	3.0	25.8
7	- 2.5	26.3	56	2.9	25.9
8	- 5.7	23.1	57	2.7	26.1
9	7.6	21.2	58	2.3	26.5
10	9.5	19.3	59	2.4	26.4
11	11.2	17.6	60	2.1	26.7
12	12.8	16.0	61	2.0	26.8
13	14.3	14.5	62	1.8	27.0
14	15.5	13.3	63	1.6	27.2
15	16.6	12.2	64	1.5	27.3
16	13.2	15.6	65	1.2	27.6
17	+ .6	28.2	66	1.2	27.6
18	- 3.1	25.7	67	.9	27.9
19	2.1	26.7	68	.8	28.0
20	4.1	24.7	69	.6	28.2
21	5.7	23.1	70	.4	28.4
22	5.6	23.2	71	.3	28.5
23	4.8	24.0	72	.2	28.6
24	3.5	25.3			
25	2.5	26.3			
26	4.4	24.4			
27	4.1	24.7			
28	5.2	23.6			
29	4.7	24.1			
30	4.3	24.5			
31	2.2	26.6			
32	3.7	25.1			
33	5.6	23.2			
34	1.1	27.7			
35	1.0	27.8			
36	7.6	21.2			
37	2.4	25.9			
38	3.0	28.5			
39	4.8	24.0			
40	3.9	24.9			
41	2.7	26.1			
42	4.4	24.4			
43	3.7	25.1			
44	3.0	25.8			
45	3.0	25.8			
46	3.8	25.0			
47	3.6	25.2			
48	3.6	25.2			

Barometer = 28.8 "Hg = 14.17 psi
= 2040 psf

${}_{A}\Delta P_B$ = 22.5 "H_2O = 117 psf

P_B = 63 psi gage

To_1 = 98 To_2 = 80°F

W_1 = .1675 #/sec

P_2 =-5.2 "Hg gage = 23.6 "Hg abs

W_2 = .1664 #/sec

M_1 = 1.895

M_2 = .57

TABLE IX

STATIC AND IMPACT PRESSURE SURVEYS: L = 13"

Static Pressures

X	P_x "Hg Gage	P_x "Hg Abs.
14	-16.1	13.73
16	-17.9	11.93
74	- 3.1	26.73
75	- 2.6	27.23
76	- 2.3	27.53
77	- 2.6	27.23
78	- 2.4	27.43
79	- 2.2	27.63
80	- 2.3	27.53
81	- 2.2	27.63
82	- 1.8	28.03
83	- 1.8	28.03
84	- 1.75	28.08
85	- 1.6	28.23
86	- 1.6	28.23
87	- 1.4	28.43
88	- 1.2	28.63
89	- 1.2	28.63
90	- 1.0	28.83
92	- .85	28.98
94	- .8	29.03
96	- .75	29.08
98	- .6	29.23
100	- .45	29.38
102	- .35	29.48
104	- .25	29.58
106	- .22	29.61
108	- .20	29.63
110	- .15	29.68
112	- .10	29.73
114	- .07	29.76
116	- .05	29.78
118	- .0+	29.83+
120	0	29.83

Impact Pressures

l	d	P_d "Hg Gage	P_d "Hg Abs.
	1/32	8.4	38.23
	1/8	12.4	42.23
	2/8	13.8	43.63
13"	3/8	14.7	44.53
	4/8	13.5	43.33
	5/8	12.2	42.03
	1/32	2.6	32.43
	1/8	8.5	38.33
	2/8	10	39.83
12"	3/8	12.3	42.13
	4/8	13	42.83
	5/8	13.5	43.33
	1/32	8	37.83
	1/8	7.6	37.43
	2/8	11	40.83
10.5"	3/8	14.8	44.63
	4/8	16.3	46.13
	5/8	17.5	47.33

L = 13"

Barometer = 29.83 "Hg = 14.66 psi = 2110 psf

To_1 = 94°F W_1 = .1673 #/sec

To_2 = 76°F W_2 = .1731 #/sec

P_2 = -5.9 gage = 23.93 M_1 = 2.31

P_B = 65 psig = 79.66 psi abs M_2 = .574

$_A\Delta P_B$ = 22.8 "H_2O

TABLE X

STATIC AND IMPACT PRESSURE SURVEYS: L = 17.125

X*	P_x "Hg Gage	P_x "Hg Abs.
0	- 3.2	26.38
1	- 3.4	26.18
2	- 3.8	25.78
3	- 3.5	26.08
4	- 3.4	26.18
5	- 3.1	26.48
6	- 3.1	26.48
7	- 3.1	26.48
8	- 3.1	26.48
9	- 3.2	26.38
10	- 2.8	26.78
11	- 2.5	27.08
12	- 2.7	26.88
13	- 2.7	26.88
14	- 2.7	26.88
15	- 2.3	27.28
16	- 2.2	27.38
17	- 2.2	27.38
18	- 2.0	27.58
19	- 2.0	27.58
20	- 1.9	27.68
21	- 1.7	27.88
22	- 1.7	27.88
23	- 1.7	27.88
24	- 1.4	28.18
25	- 1.5	28.08
26	- 1.3	28.28
27	- 1.2	28.38
28	- 1.1	28.48
29	- 1.0	28.58
30	- 1.0	28.58
31	- .2	29.38
32	- .7	28.88
33	- .5	29.08
34	- .4	29.18
35	- .4	29.18
36	- .35	29.18
37	- .2	29.38
38	0	29.58
39	+ .1	29.68
40	.2	29.78
41	.5	30.08
42	.55	30.13
43	.4	29.58
44	.5	30.08
45	.5	30.08
46	.5	30.08
47	.6	30.18
48	.6	30.18
49	.6	30.18
50	.6	30.18
52	.8	30.38
54	.7	30.28
56	.7	30.28
58	.7	30.28
60	.6	30.18
62	.4	29.98
70	.4	29.98
78	.35	29.88

IMPACT SURVEYS

	d	P_d "Hg Gage	P_d "Hg Abs
l = 9.5"	1/8	16	45.58
	2/8	21.5	51.08
	3/8	23.5	53.08
	4/8	20	49.58
	5/8	18.8	48.38
	1/32	9.5	39.08
l = 10.5"	1/8	16	45.58
	2/8	20	49.58
	3/8	19.5	49.08
	4/8	19.5	49.08
	5/8	18	47.58
	1/32	9	28.58
l = 11.5"	1/8	15.5	45.08
	2/8	20	49.58
	3/8	20.2	49.78
	4/8	18	47.58
	5/8	17	46.58
	1/32	10.4	39.98

Barometer: 29.58 "Hg

*X has 0 position at 6.125" from primary discharge, and measure in 1/8 inches.

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TABLE XI

STATIC TRAVERSE OF FREE JET DISCHARGE

X	P_x "Hg Abs.
2"	13.9
2 1/40	22.1
2 2/40	25.9
2 3/40	27.8
2 4/40	31.4
2 5/40	33.6
2 6/40	35.0
2 7/40	36.6
2 8/40	38.4
2 9/40	38.4
2 10/40	35.4
2 11/40	32.4
2 12/40	28.6
2 13/40	26.9
2 14/40	27.4
2 15/40	32.9
2 16/40	35.9
2 17/40	37.9
2 18/40	39.9
2 19/40	39.9
2 20/40	39.9
2 21/40	38.9
2 22/40	36.9
2 23/40	34.3
2 24/40	32.7
2 25/40	30.9
2 26/40	28.2
2 27/40	27.9
2 28/40	27.5
2 29/40	27.3
2 30/40	26.5
2 31/40	27.9
2 32/40	26.2
2 33/40	24.4
2 34/40	23.1
2 35/40	23.4
2 36/40	24.6
2 37/40	26.2
2 38/40	30.9
2 39/40	34.1
3	37.4
3 1/40	36.4
3 2/40	35.1
3 3/40	32.9
3 4/40	31.7
3 5/40	30.7
3 6/40	29.9
3 7/40	29.4
3 8/40	29.3
3 9/40	29.6
3 10/40	29.9
3 11/40	31.7
3 12/40	32.1
3 13/40	32.9
3 14/40	32.9
3 15/40	31.5
3 16/40	31.2
3 17/40	29.9
3 18/40	29.6
3 19/40	28.5
3 20/40	28.1
3 21/40	27.9
3 22/40	27.6
3 23/40	28.3
3 24/40	28.0
3 25/40	27.8
3 26/40	28.3
3 27/40	28.3
3 28/40	28.9
3 29/40	30.9
3 30/40	32
3 31/40	32.1
3 32/40	32
3 33/40	31.5
3 34/40	30.9
3 35/40	29.9
3 36/40	29.9
3 37/40	29.9
3 38/40	29.9
3 39/40	29.8
4	29.7
4 1/40	29.4
4 2/40	29.6
4 3/40	29.7
4 4/40	30
4 5/40	30.1
4 6/40	30.6
4 7/40	31.3
4 8/40	31.4
4 9/40	31.4
4 10/40	31.3

Barometer = 28.85 "Hg

${}_A\Delta P_B$ = 23.1

P_B = 65 psig

To_1 = 90

TABLE XII

IMPACT SURVEYS L = 17.187

$_A\Delta P_B$	P_B	P_2	T_{01}
"H_2O	Psi Gage	"Hg Gage	°F
23	64	- 5.6	85

IMPACT SURVEYS

Barometer = 30.12

To_2 = 70°F

l	d	P_x
		"Hg Abs
17.187	1/32	37.7
	1/8	39.3
	2/8	40.1
	3/8	40.6
	4/8	40.1
	5/8	42.1
15.562		36.1
		38.6
		39.3
		39.5
		39.5
		39.6
13.562		35.8
		38.7
		40.1
		39.8
		39.6
		40.1
11.562		36.5
		39,7
		42.1
		41.6
		40.3
		41
8.562		33.8
		38.4
		40.3
		43.1
		43.2
		43
6.562		30.4
		34.1
		38.1
		46.1
		47.1
		47.1